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Feasibility of Potato Production in Hawaii

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FEASIBILITY OF POTATO PRODUCTION IN HAWAII

Luis A. Manrique

ABSTRACT

Hawaii has a long history of unsuccessful potato production that is practically unknown to the agricultural community. Crop failure due to disease and insect attack, lack of available seed, improper crop and soil management, and overseas competition for the local market have reduced potato production in Hawaii to a backyard activity. However, Hawaii possesses extensive lands that are suitable for potato production. With appropriate inputs of locally adapted technology, such lands can produce enough potatoes for local consumption.

Keywords: tropical root crop, tropical soils, *Solanum tuberosum.*

HISTORY

The Irish potato is a crop of ancient origin. Long before the Spaniards arrived in South America in the 16th century, the potato had already been cultivated for 9000–10,000 years (Hawkes, 1978). The potato arrived in Europe during the last quarter of the 16th century. Although there is no doubt that European potatoes belong to the species *Solanum tuberosum,* there has been considerable controversy as to what region of South America they came from. Since the Andean subspecies *S. andigena* forms tubers in short-day seasons, it seems that early *andigena* introductions to Europe would change after 200–300 years into the subspecies *S. tuberosum.* In North America the potato was unknown until the early 17th century. The first North American potatoes were grown in Virginia.

The potato was introduced to Hawaii by 1813 (Crawford, 1937). Although it was occasionally planted by Hawaiians, it was rarely seen in the markets before 1835. By 1840, plantings were already spreading in the uplands of Maui and Oahu. During the early years of the California gold rush, there was a great demand for Hawaiian potatoes at almost unbelievable prices. From 1848 to 1851, Hawaii potatoes ranked first among commodities shipped to the United States. By 1854, California began to produce potatoes again and shipment to Hawaii resumed, whereupon producers in Hawaii stopped growing potatoes even for local needs. In a few years, the once-flourishing potato industry disappeared almost completely.

In 1932, the potato industry was revived in Hawaii. The sugar and pineapple indus-

Table 1. Cultivated area, production and yield of potato in Hawaii for selected years (Sources: Hawaii Agricultural Reporting Service, 1976, 1979, 1980; Philipp, 1953)

Year	Cultivated area	Production	Yield
	(acres)	(1000 lb)	(metric tons/ha)
1909	353	-†	-
1919	405	-	-
1929	214	-	-
1939	487	-	-
1941	680	6787	11.2
1944	1289	7831	6.8
1947	64	355	6.2
1950	131	645	5.5
1955	85	555	7.3
1960	65	455	7.8
1965	70	470	7.5
1970	75	500	7.5
1971	105	1095	11.6
1972	35	375	12.0
1973	370	5871	17.8
1974	295	4650	17.7
1975	230	4041	19.7
1976	5	65	14.5
1977	6	75	14.0
1978	0	0	0

†Data not available.

tries had suffered from unstable markets and falling prices. Extensive areas of both crops were abandoned. Efforts were made to replace pineapple and sugarcane with new crops; field experimentation with potatoes was encouraging. Most of the credit for this effort is due the Hawaii Agricultural Experiment Station. Potato trials were conducted in an effort to discover some varieties resistant to diseases and insect attack. Krauss and Nishimura (1934) made an alphabetical list of 60 varieties indicating seed source, length of growing season in Hawaii, number of growers, cultivated area, average yields, tuber quality, and so on. The efforts to increase potato production were also supported by studies on costs of production and marketing in Hawaii and on the U.S. mainland (Lund, 1932, 1933*a*, 1933*b*, 1934; Smith, 1935; Warner, 1936).

Cultivated area in potatoes doubled from 1929 to 1939 and almost tripled from 1939 to 1944 (Table 1). By 1935, potatoes (especially the winter crop) grown for export became a profitable industry in Hawaii. Winter potatoes found a ready market on the Pacific coast, arriving early before the U.S. winter potato crop was available (Moir, 1937*a*, 1937*b*; Anonymous 1934, 1941; Smith, 1935).

By 1944, the potato crop was thought to be a permanent industry in the Hawaii agricultural system (Ruddle, 1944). However, after that year, production declined so quickly that by 1947 only 64 acres were cultivated. Although no definite reasons have been found, it now seems that postwar mechanical technology, which was diverted to agriculture, lowered the costs of U.S. potato production so much that it became impossible for Hawaii potatoes to compete in local and overseas markets. Thus, potato production in Hawaii was reduced to a backyard activity until 1973, when some potato growers from California tried to revive the industry again. The attempt lasted three years. Unfortunately, the use of machinery in potato production created tensions with the local labor union and the attempt was ended. By 1978, no commercial growing of potatoes was reported (Hawaii Agricultural Reporting Service, 1979).

LOCAL CONSUMPTION

The U.S. civilian per capita consumption of potatoes was 105 lb (48 kg) in 1960 and 123 lb (56 kg) in 1979 (Hawaii Agricultural Reporting Service, 1980). No data are available for Hawaii; however, a good estimate of the annual per capita consumption would be 60 lb (27 kg). Potato as a fresh product is not a main ingredient in the local daily diet. Most of the potatoes imported are used for processed food.

In this study, the potato inshipments to Hawaii are used as an indicator of local potato consumption. Data taken from Crawford (1937) and Elliott (1952) show that the average annual inshipment for the period 1911-1951 was as follows:

Year	Annual inshipment	
	(10^6 lb)	(10^6 kg)
1911-1915	11.8	5.4
1921-1925	17.4	8.1
1935	18.5	8.4
1951	20.4	9.3

Inshipments from 1954 through 1978 are presented in Figure 1. The results indicate an increasing trend in local consumption. The potato inshipment in 1978 was almost 3 times the amount imported in 1915. The inshipment in 1978, however, was only 1.4 times the inshipment in 1954. Except for some cutbacks in potato inshipments from 1973 through 1976, the general upward trend indicates a steadily growing demand for potatoes. If this is correct, the total local potato consumption by 1985 would be around 44 million lb (20 million kg).

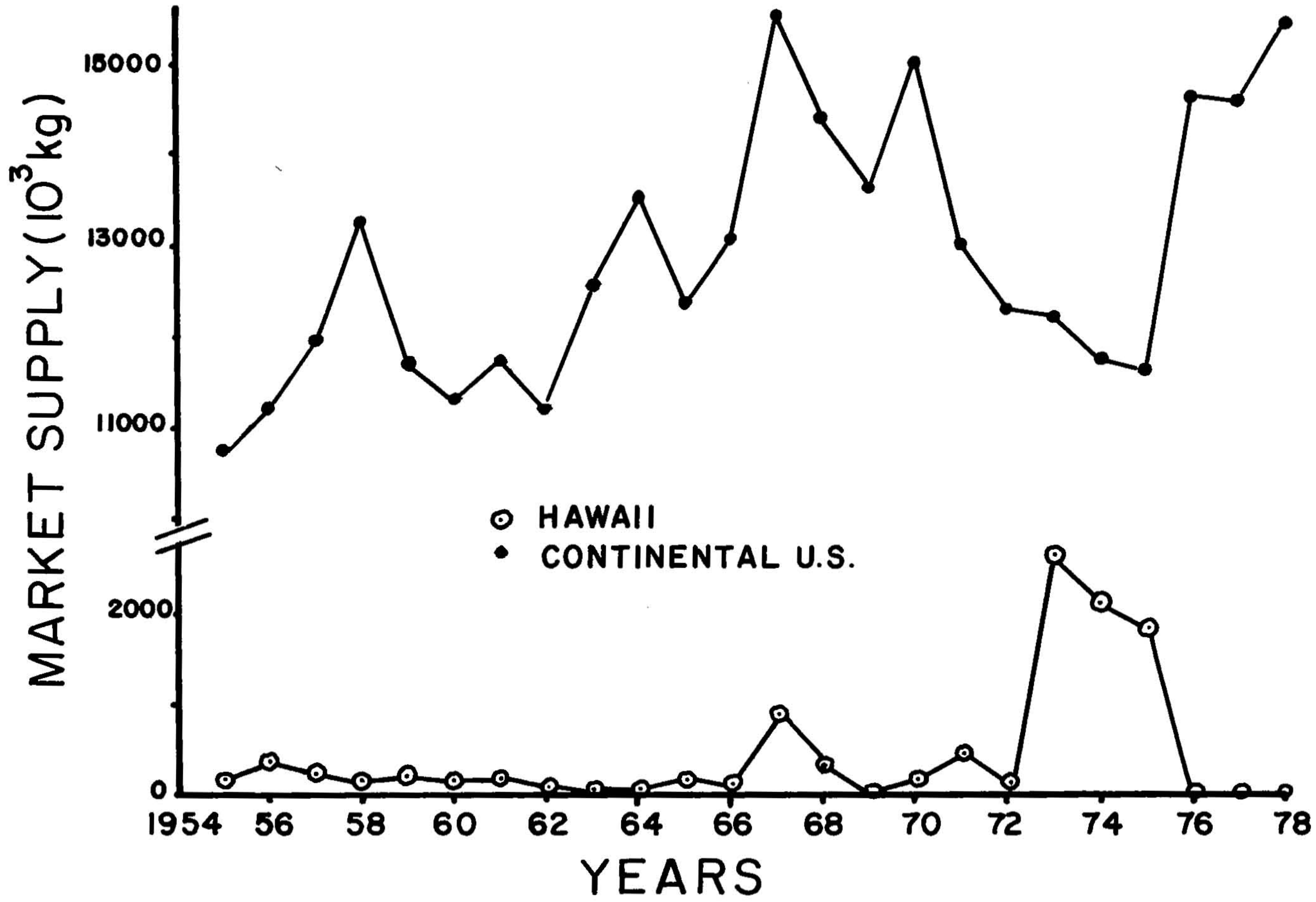

Figure 1. Potato supplies for food processing and fresh market in Hawaii. (Source: Hawaii Agricultural Reporting Service, 1976, 1979)

LOCAL PRODUCTION

Current

The maximum production in Hawaii was 11.3 million lb (5.1 million kg) in fiscal year 1937 (Philipp, 1953). In 1973, production was close to 5.9 million lb (2.7 million kg). Current production is negligible (Figure 1).

Potential

Yield per unit area, farm prices, and the gross income per unit area are presented in Figures 2 and 3. Yields were low and constant (7 metric tons/ha) from 1955 to 1965. Yields in the continental United States for the same period increased from 18 to 22 metric tons/ha. From 1965 to 1975, local yields increased from 7 to 20 metric tons/ha. Yields in the continental United States for the same period increased from 22 to 29 metric tons/ha.

The 1975 local yields were scarcely comparable with the 1955 yields in the continental United States. This span in time and yields between the U.S. mainland and Hawaii stresses the effects of high levels of input and technology on U.S. potato production. However, relatively high local yields for the period 1972–1975 (which coincided with the cultivation of potatoes by some California growers on Maui) reveal that yields in Hawaii can be increased by the application of more and better technology.

Local people show special preference for the homegrown Hawaii potatoes. In fact, the data in Figure 3 show that local potato growers in the past obtained better farm prices than U.S. farmers. Further calculation of the gross income per unit area reveals that, because of the high prices per pound, local growers received a high gross income per unit area even though yields were low. The data in Figure 3 indicate that potato production in Hawaii could become a highly profitable activity if tuber yield were increased. However, increasing the yield per unit area involves the application of inputs and technology, including preplanting and postharvest technology that local farmers do not possess.

But Hawaii does possess land with potential to grow potatoes. Such areas are extensive on the island of Hawaii. Assuming that by 1985 Hawaii will consume 44 million lb of potatoes, and assuming that by 1985 improved technology increases average farm yields to 20 metric tons/ha, the state of Hawaii will be required to cultivate 2200 acres (1000 ha) to meet local needs. The cultivation of only one soil phase (Kukaiau silty clay loam, 6–12 percent slope, 2871 acres), for example, would be sufficient to cover local consumption. That area would represent barely 1 percent of the total land on the island of Hawaii.

POTATO RESEARCH IN HAWAII

Potato production in Hawaii has been neglected for the past 40 years, and there is presently no locally developed technology to produce potatoes. In 1930, however, a group of scientists led by F. G. Krauss adapted U.S. technology to local conditions. The use of this adapted technology resulted in high yields for a short time; local growers produced high quality potatoes for export and local consumption. Although most of the research conducted during the period 1930–1940 is almost irrelevant at the present time, it is worthwhile to analyze the problems that potato production experienced at that time.

Disease and pest control was the main problem in potato production. Hawaiian growers depended completely on potato seed shipped from the U.S. mainland, and the general concern was to develop ways to prevent and control diseases carried with the seed (Porter and Burns, 1933; Ressler, 1935; Schultz et al., 1937). Wide publicity was given to methods developed locally and on the mainland to control virus diseases (Bonde et al., 1943; Folsom, 1941); common scab, *Streptomyces scabies* (Cunningham and Wes-

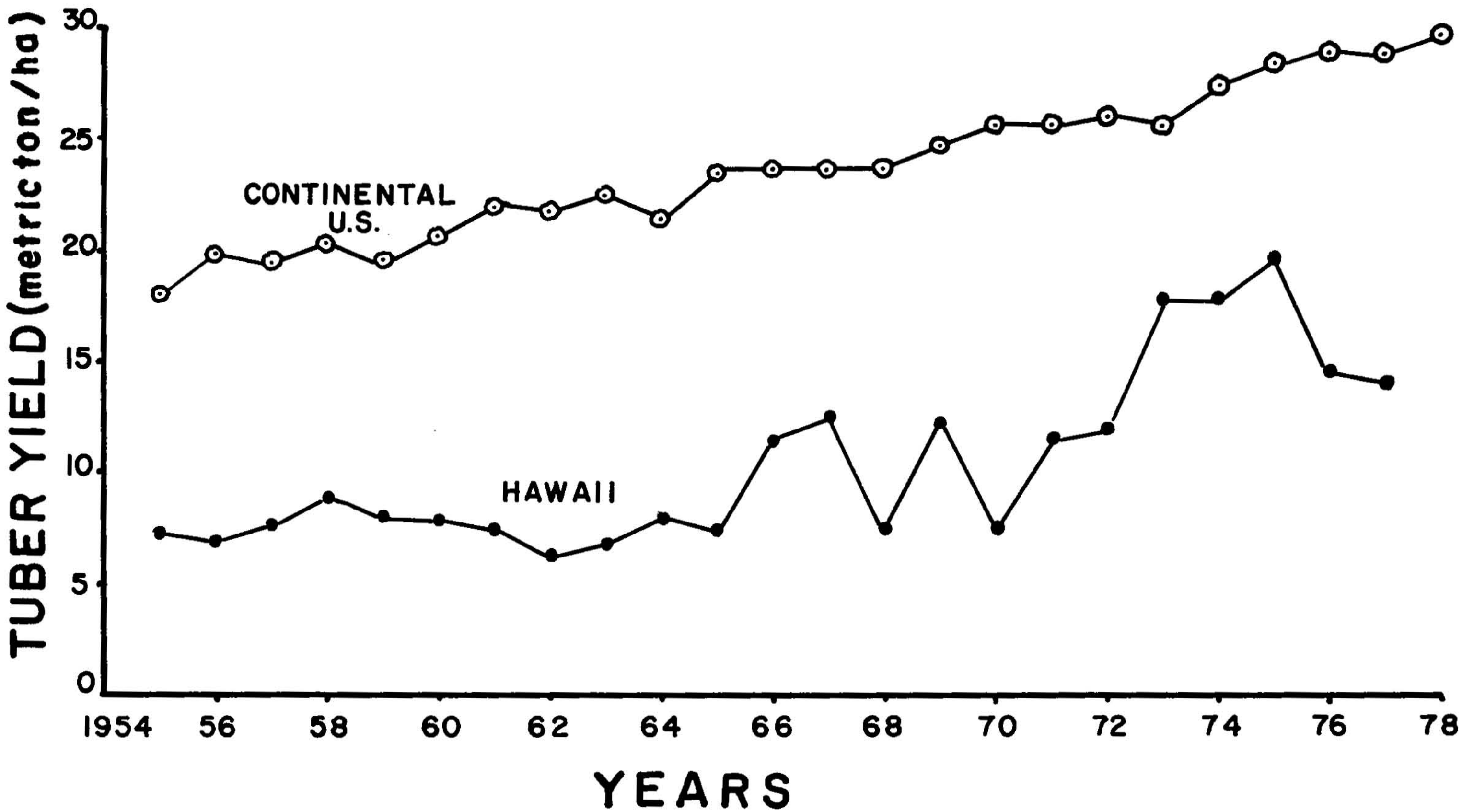

Figure 2. Potato yields in Hawaii and the continental United States. (Sources: FAO, 1969, 1970, 1974, 1979; Hawaii Agricultural Reporting Service, 1976, 1979)

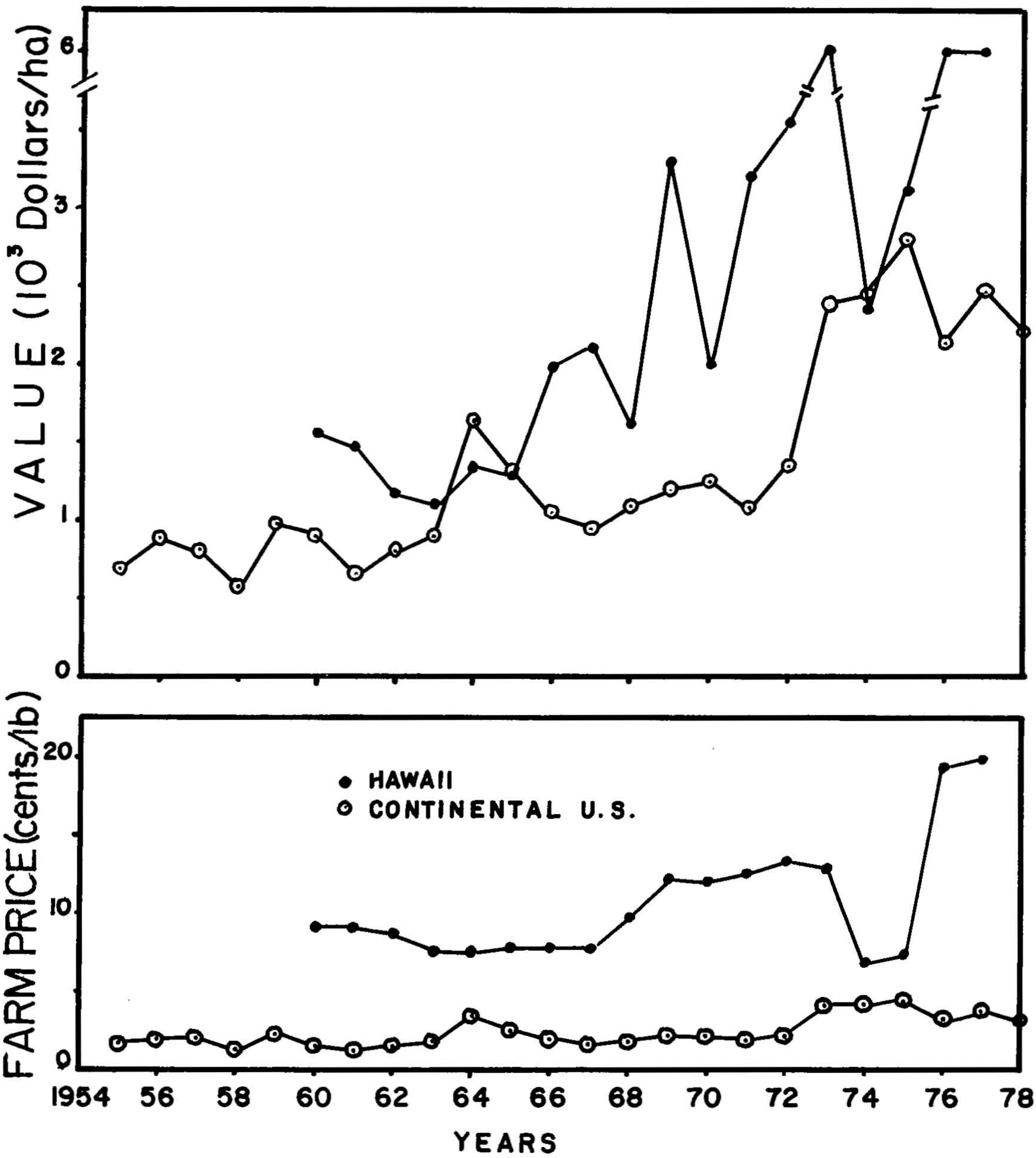

Figure 3. Potato farm prices and gross income/ha in Hawaii and the continental United States. (Sources: FAO, 1969, 1970, 1974, 1979; Hawaii Agricultural Reporting Service, 1976, 1979)

sels, 1939; Knight, 1941; Lutman, 1943); bacterial ring rot, *Erwinia carotovora* (Brentzel and Munro, 1940; Carpenter, 1940); rhizoctonia, *Rhizoctonia solani* (Carpenter, 1935*a*); and late blight, *Phythophthora infestans* (Carpenter, 1935*b*; Schultz and Haskell, 1943).

Continual field inspections were conducted in large-scale potato fields on Oahu reporting occurrences of insects and changes in population after control (Carpenter, 1935*c*, 1936; Chung, 1931; Krauss, 1933*a*; Pemberton, 1939; Poos, 1942; Swezey, 1937). Nematode infestation was also a severe problem (Carpenter and van Zwaluwenburg, 1938; Parris, 1948; van Zwaluwenburg and Carpenter, 1939).

In addition, studies were conducted on potato dormancy and methods to enhance tuber sprouting (Krauss, 1932*a*, 1932*b*, 1933*b*, 1933*c*, 1933*d*; Michener, 1940*a*, 1940*b*; Niven, 1932; Nishimura, 1934); however, very few studies were conducted on agronomic practices, including fertilizer use (Browne, 1940; Carpenter, 1935*d*; Edwards, 1937).

After 1970, some potato breeding studies were conducted by Sekioka et al. (1974) and Ito et al. (1978). Two new varieties, 'Waimea' and 'Pele', with high tolerance to late blight (*Phytophthora infestans*), were tested in different environments on the island of Hawaii. According to the authors, these varieties are specially adapted to elevations higher than 800 m and produced much greater yields than 'Kennebec' if late blight infestations were serious. No recent developments in these varieties have been published and no commercial production has been reported.

AGRONOMIC ASSESSMENT IN HAWAII ENVIRONMENTS

The main assumption for a profitable potato industry in Hawaii is the production of high tuber yields at a low cost. To test the validity of this assumption a network of potato trials was conducted in three environments in Hawaii: Waipio (island of Oahu), Kukaiau, and Kohala (both island of Hawaii). The Waipio and Kukaiau experiments were conducted on the Benchmark Soils Project sites (Ikawa, 1979), and the Kohala experiment was conducted on the Kohala Vegetable Farm. Certified seed pieces of 'Kennebec', a mainland cultivar, were used in all experiments.

Plots measuring 8 X 3 m, with rows 75 cm apart, were seeded with potatoes spaced 35 cm apart in rows to achieve a density of 36,666 plants/ha. Nitrogen (N) fertilizer was applied in Waipio at the rate of 160 kg/ha and potassium (K) at 120 kg/ha. The Kukaiau plots received 160 kg of N and 166 kg of K/ha. These two sites were not fertilized with phosphorus (P) because previous results indicated that corn did not respond to P fertilizers. The Kohala plots received 160 kg of N/ha, 89 kg of P/ha, and 166 kg of K/ha. In all experiments, half of the N was applied at planting and half 30 days after planting.

Irrigated and nonirrigated treatments in a completely randomized design with six replications were included in most experiments. All experiments were irrigated for the first 30 days to achieve adequate emergence. After this, water was applied in designated plots whenever soil water tension reached 0.50 bars. Soil temperatures were measured at 0, 10, 20, and 50 cm depths during the growing season.

Plant growth, tuber initiation and tuber enlargement, and plant nutrient content were monitored 40, 60, 80, and 100 days after planting. Planting and harvest dates for each experiment were as follows:

Site	Season	Year	Planting	Harvest
Waipio	Winter	1980	Dec. 20	March 30
	Summer	1980	June 26	Oct. 22
	Winter	1981	Jan. 14	April 22

Site	Season	Year	Planting	Harvest
Kukaiau	Summer	1980	July 01	Oct. 28
	Winter	1981	Jan. 20	May 08
Kohala	Winter	1981	Jan. 19	April 28

The Kohala experiment included windbreak and irrigation treatments arranged in a split-plot design with windbreaks as the main plots and irrigation treatments as subplots. The windbreak treatments were fine net with 2 mm opening, sugarcane, and control (unprotected). The windbreaks were 2 m high and surrounded the main plots. They were oriented to protect crops against the northeasterly trade winds.

Ustic Humitropepts

The Kohala area on the island of Hawaii is located on the windward side of the Kohala range. Most of the soils in the Kohala area belong to the Kohala series (Ustic Humitropepts) (Sato et al., 1973). In the Kohala area, a long history of sugarcane production ended a few years ago, releasing extensive areas for diversified agriculture. One alternate use considered for these areas was pasture production. Later, experiments were conducted with several different crops to study their response and adaptation to wind. The potato experiment reported here was a part of that effort (Manrique, 1981).

Agroenvironment. The soil at the Kohala site is a member of the very fine, mixed, isohyperthermic family of Ustic Humitropepts. Soils of the Kohala series are well-drained, deep, silty clay, with mixed mineralogy dominated by kaolinite and goethite (Soil Conservation Service, 1976). Chemical analysis of this soil is presented in Table 2. Only rainfall and pan evaporation data have been collected in the Kohala area for the period 1880–1970 (Figure 4). The annual rainfall and water evaporation trends show a continuous water deficit in most of the year at Hawi town (elevation 168 m), located 0.5 km above the Kohala station. Rainfall in Iole (elevation 500 m), located 5.6 km from Hawi, exceeds evaporation in seven months out of the year.

Wind is one of the main constraints to crop production in the Kohala area. Wind data collected for several experimental sites are presented in Figure 5. Two sites, Iole and Halawa, are located in the Kohala area. Their wind velocities fluctuate between 13 and 15 km/hour.

Plant growth. At 22 days after planting, emergence in windbreak treatments was 92 percent with fine net, 85 percent with sugarcane, and 99 percent in the control plot. From February 12 through February 15, strong, gusty winds affected the Kohala area. Wind damage to potato plants was recorded by randomly selecting five sets of 20 plants from each treatment. The proportions of damaged plants (burned leaves and broken stems) were 42 percent with fine net, 36 percent with sugarcane, and 66 percent in the control plot. The fine net windbreak, designed to guard against the northeasterly trades coming from the ocean, was ineffective against kona storms (local gusty winds).

Under irrigation, tuber initiation began 40 days after planting in fine net and control plots (Figure 6). Only 60 percent of the plants began tuber initiation at 40 days in sugarcane plots. Late emergence in sugarcane plots, rather than wind, accounted for the late tuber initiation.

Tuber enlargement was rapid in the fine net plots with irrigation. At 80 days, tuber weight was 1000 g/plant. The trend of tuber accumulation up to this growth period was similar or superior to tuber accumulation trends obtained for the same variety in a similar season in Waipio during 1980 and 1981 (Manrique et al.,1984). However, there was no further tuber weight increase after 80 days. Tuber enlargement after 80 days was virtually stopped by rhizoctonia (*Rhizoctonia solani*) infestation.

Table 2. Selected chemical properties (Sources: Ikawa, 1979; Soil Conservation Service, 1976)

Horizon	Depth	pH	Al	K	ECEC†	Al Sat.	O.M.
	(cm)	(KCl)	---- meq/100 g ----			------ % ------	
			Kohala Series				
Ap1	0-18	4.9	0.3	0.5	12.0	2.5	4.62
Ap2	18-35	5.0	0.1	0.1	11.4	0.8	4.13
B21	35-68	5.6	0.1	0.1	8.4	1.1	1.67
B22	68-98	5.8	--‡	0.1	--	--	1.14
			Wahiawa Series				
Ap1	0-10	4.8	0.0	2.7	13.7	0.0	4.0
Ap2	10-27	4.2	0.3	0.9	8.6	3.5	2.9
AB	27-40	4.5	0.1	0.1	9.4	0.5	2.4
B22	40-65	5.1	0.0	0.2	6.6	0.0	1.0
			Kukaiau Series				
Ap1	0-17	5.4	0.0	0.5	3.2	0.0	12.7
Ap2	17-23	5.5	0.0	0.1	2.0	0.0	11.3
B21	23-42	5.6	0.0	0.03	2.1	0.0	9.8
B22	42-60	5.8	0.0	0.03	2.2	0.0	8.9

†ECEC = Sum of exchangeable bases plus exchangeable Al.
‡Data not available.

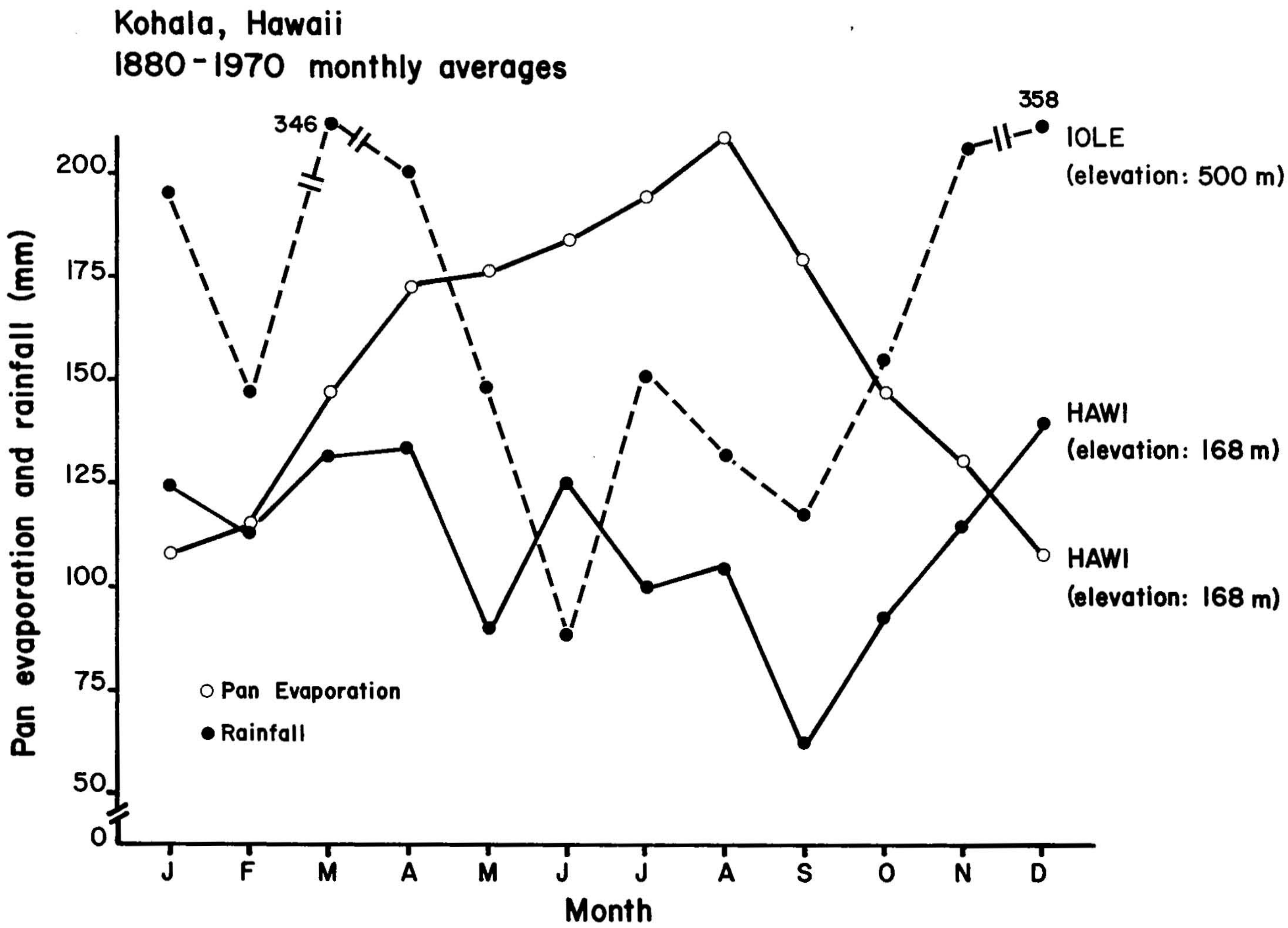

Figure 4. Average climatic data measuring pan evaporation and rainfall in the Kohala area during the years 1880 to 1970. (Source: Manrique, 1981)

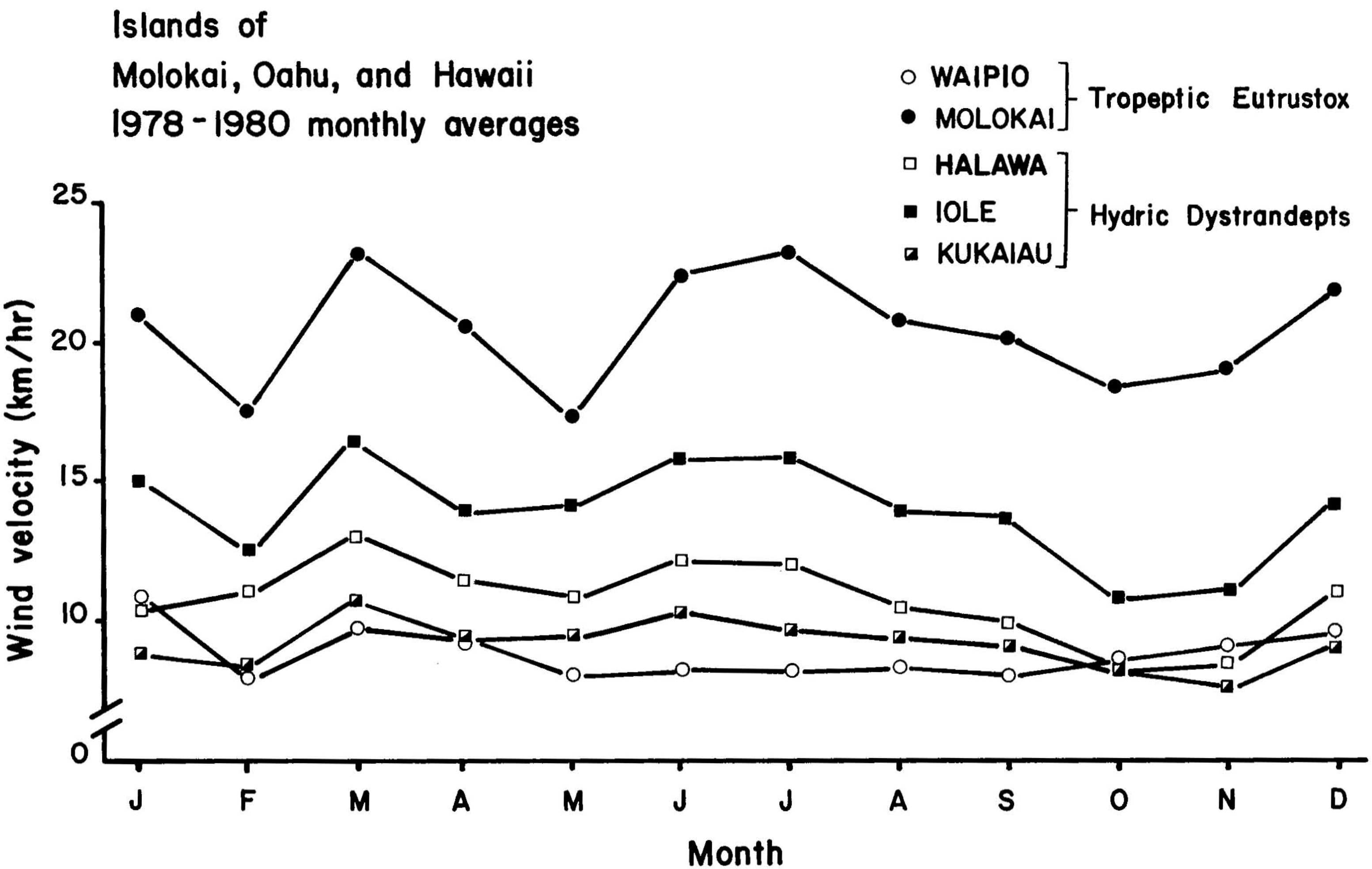

Figure 5. Wind velocity of various Benchmark Soils Project experimental sites in Hawaii measured in 1978 to 1980. (Source: Manrique, 1981)

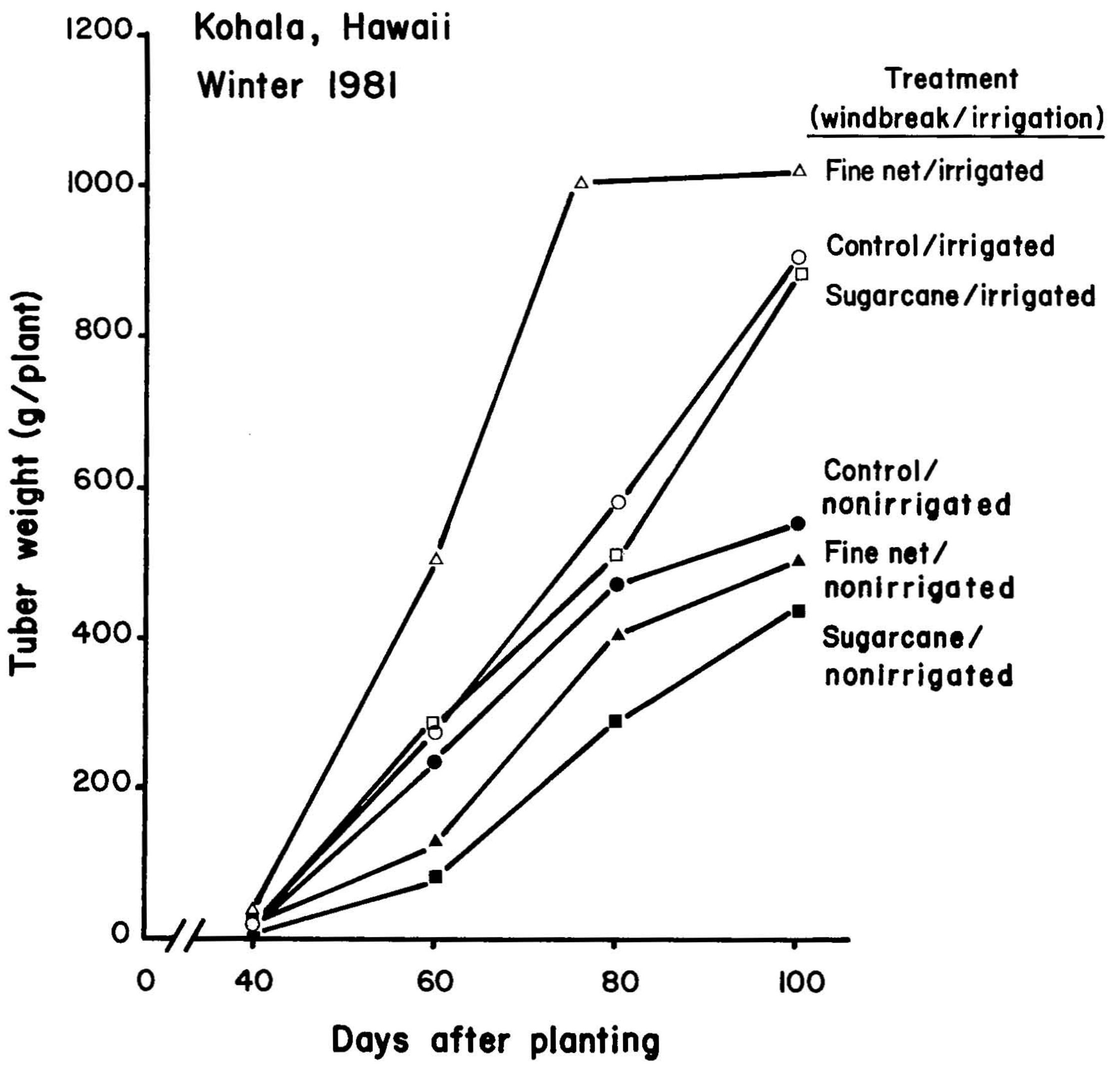

Figure 6. Effects of irrigation and windbreaks on accumulation of fresh weight in potato tubers at Kohala, winter 1981. (Source: Manrique, 1981)

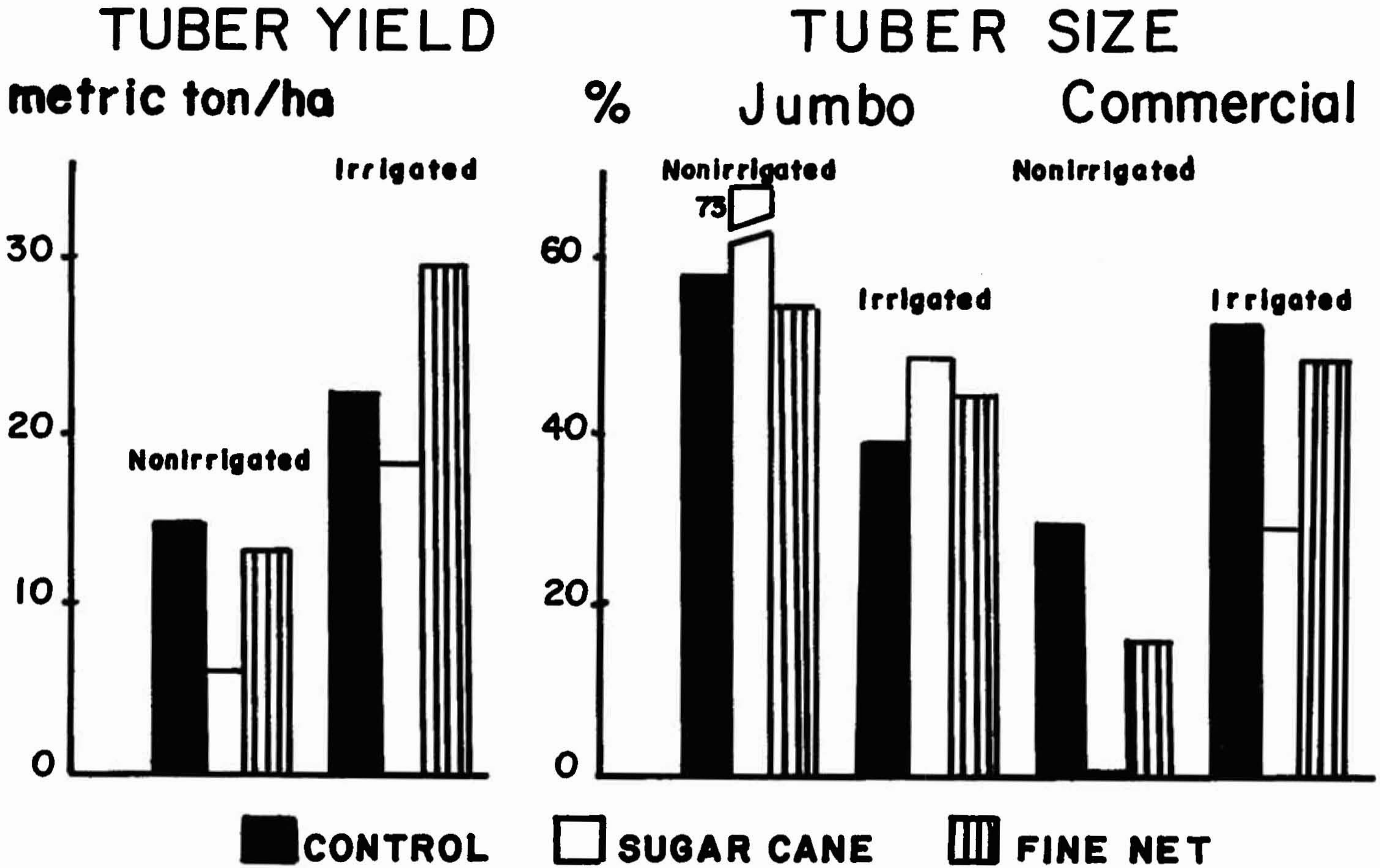

Figure 7. Effects of irrigation and windbreaks on potato tuber yields and tuber size at Kohala, winter 1981. (Source: Manrique, 1981)

Comparisons of tuber weight per plant between irrigated fine net and control plots show that plants grown in fine net plots (Figure 6) accumulated more tuber weight per plant than those grown in control plots. Greater tuber weights in fine net plots are attributed to the protection provided by the net windbreak.

Without irrigation, tuber weight accumulation of plants grown in both fine net and sugarcane plots was lower than that of plants grown in control plots (Figure 6). No substantial differences in tuber weight were found between plants grown in irrigated and nonirrigated control plots up to 80 days. Both plots were surrounded by other crop experiments that were sprinkler irrigated. Spray drift caused by strong winds may have supplied water to the nonirrigated control plots.

Yields in the nonirrigated fine net plots were 43 percent of yields in irrigated fine net plots (Figure 7). Yields in nonirrigated control plots were 64 percent of yields in irrigated control plots.

Lack of irrigation also reduced the number of tubers of commercial size. For example, 49 percent of the tuber yield in irrigated fine net plots were of commercial size, in comparison to 16 percent of the tuber yield in nonirrigated fine net plots. The results indicate that water stress delayed tuber initiation and shortened the period for tuber enlargement. Hence, very few tubers reached commercial size.

Among windbreak treatments, the irrigated fine net plots yielded best. However, yields were lower than those obtained in Waipio during the winter season (see page 21).The virtual stoppage of dry matter accumulation in tubers at 80 days (due to a late rhizoctonia infection) probably accounted for the lower yields in Kohala.

Pest and disease aspects. Mechanical injury to leaves and stems due to wind and subsequent disease infestation were the main problems in the Kohala experiment. Some symptoms due to alternaria (*Alternaria solani*) were observed after a windstorm early in the winter season of 1981.

Although there was no apparent relationship between wind damage and rhizoctonia (*Rhizoctonia solani*) infection, severely damaged plants in the Kohala experiment may have been more susceptible to rhizoctonia infestation. Rhizoctonia infection was severe and almost destroyed the plant canopy in some control plots. No symptoms of late blight (*Phytophthora infestans*) or nematode attack were observed.

Tropeptic Eutrustox

The Tropeptic Eutrustox are oxide-rich soils of the stable landscapes of the tropics. Members of this soil have been identified in Hawaii, Puerto Rico, and Brazil (Ikawa, 1979).

Agroenvironment. The soil at the Waipio site belongs to the Wahiawa series (Foote et al., 1972) and is a member of the clayey, kaolinitic, isohyperthermic family of Tropeptic Eutrustox. Chemical analysis of these soils is presented in Table 2.

Potential evapotranspiration calculated according to Hargreaves (1974) and climatic data recorded during the period 1980–1981 are presented in Table 3. Except for the winter months (January–March), when rainfall was approximately equal to pan evaporation or potential evapotranspiration, the rest of the year was characterized by a continuous water deficit.

The mean air temperature during the winter months in 1980 was 1 to 2 °C cooler than air temperature during the winter in 1981. Air temperature during the summer months (June–August) in 1980 was around 25 °C.

Soil temperatures at 82 days after planting are presented in Figure 8. Night soil temperature is given because it affects tuber initiation and enlargement more than day soil

Table 3. Rainfall, pan evaporation, potential evapotranspiration, and air temperature for Waipio (island of Oahu) (Source: Benchmark Soils Project, University of Hawaii)

Year	Month	MAT (1)	Rainfall	Pan evaporation	ETP (2)
		°C	------------	mm	------------
1980	January	21.5	316	136	85
	February	22.0	76	125	112
	March	23.4	100	143	127
	April	24.3	80	161	145
	May	24.3	54	182	171
	June	24.5	96	192	152
	July	25.2	86	202	166
	August	25.4	40	182	166
	September	23.2	65	196	132
	October	25.0	90	143	108
	November	24.8	47	152	101
	December	24.0	134	108	80
1981	January	23.7	58	- †	82
	February	23.1	82	-	98
	March	23.0	56	-	118
	April	23.5	42	-	-

(1) Mean air temperature.
(2) Potential evapotranspiration (Hargreaves method, 1974).
† Data not available.

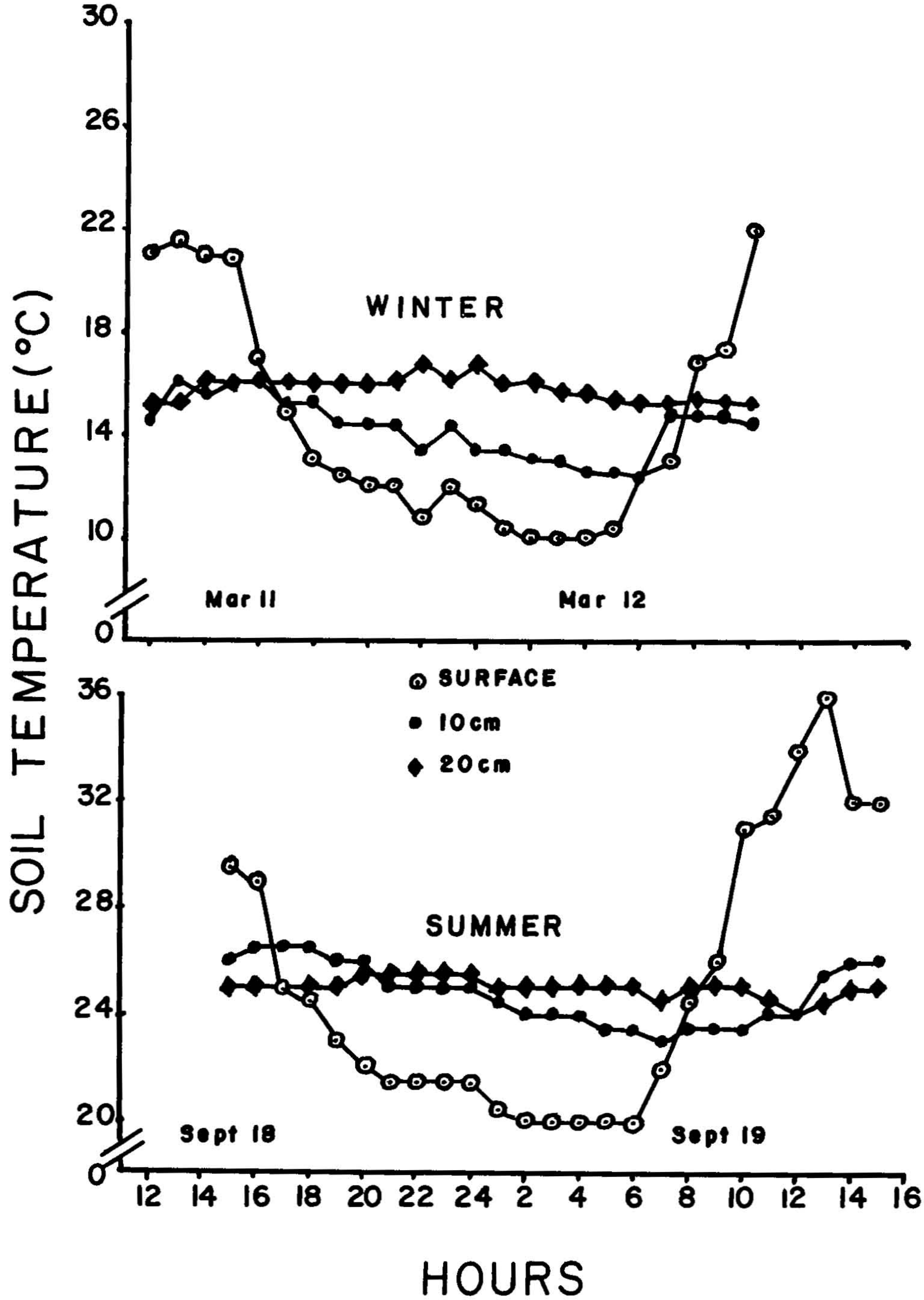

Figure 8. Soil temperature measured at various depths in irrigated potato plots at Waipio, winter and summer 1980. (Source: Manrique et al., 1984)

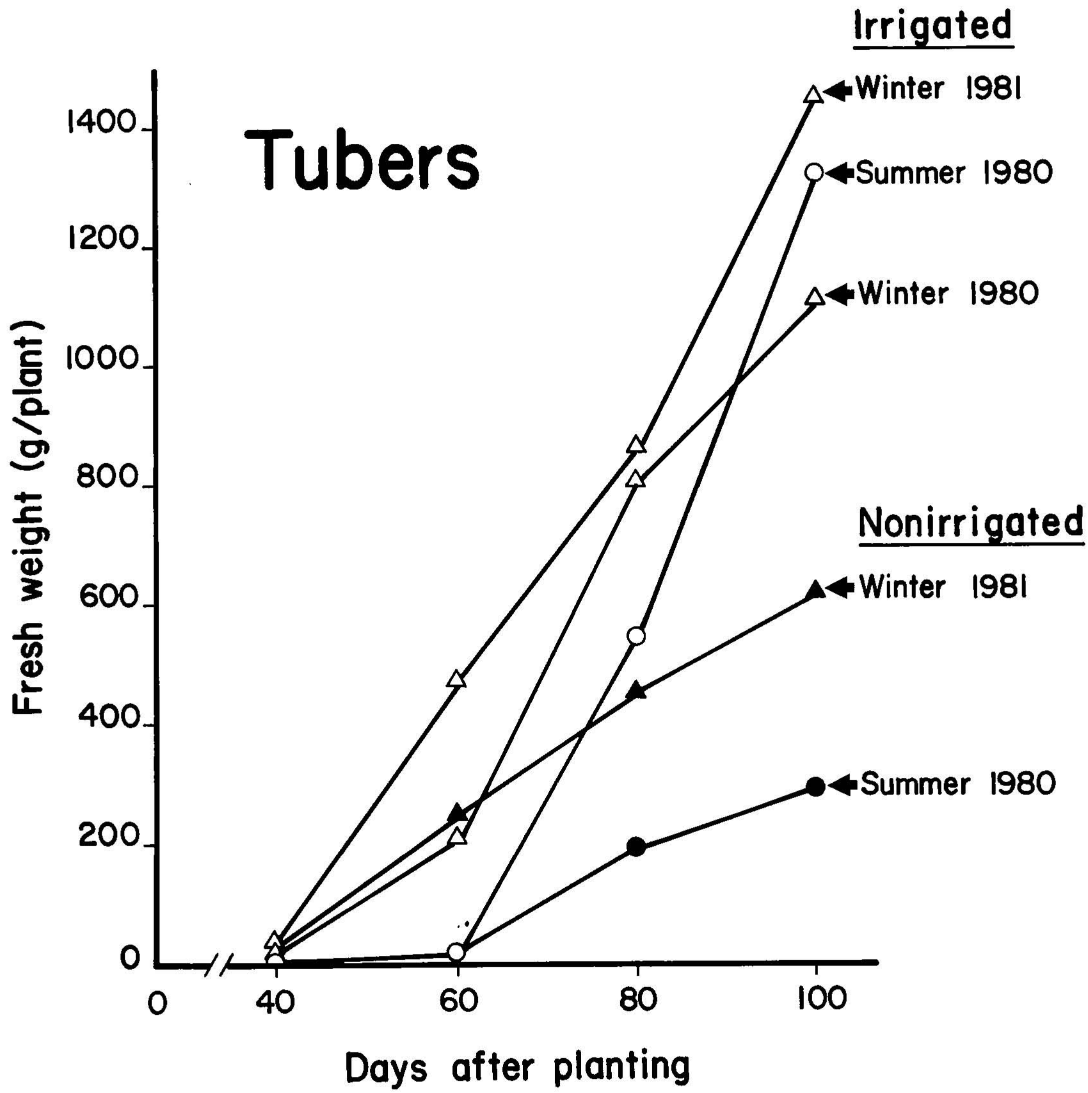

Figure 9. Effect of irrigation on accumulation of fresh weight in potato tubers at Waipio, winter and summer 1980 and winter 1981. (Source: Manrique et al., 1984)

temperature (Bodlaender, 1963).

At the depth of tuber set (10 cm), soil temperatures in the winter and summer of 1980 were 13 to 15 °C and 23 to 27 °C, respectively. The soil temperature data in Figure 8 indicate that tuber enlargement in this Tropeptic Eutrustox of Hawaii proceeded under different soil temperatures for summer and winter seasons.

Plant growth. Tuber initiation and enlargement in the winter began just before 40 days after planting (Figure 9). Fresh tuber weight per plant in the winter of 1981 was approximately 863 g at 80 days and 1451 g at 100 days. A similar accumulation pattern was found in the winter of 1980.

Tuber initiation in the summer was delayed until 55 days after planting. The fresh tuber weight per plant in the irrigated plots was 544 g at 80 days and 1322 g at 100 days.

Without irrigation the fresh tuber accumulation rate in the winter was higher than in the summer. Since plants were taken at comparable growth periods through the season, the greater tuber accumulation rate in the winter (nonirrigated treatments) appears to be a consequence of lower soil temperatures.

The highest tuber yields were obtained in the winter season (Table 4). Yields varied between 34 and 39 metric tons/ha. Summer yields of irrigated plots were between 66 and 74 percent of winter yields of irrigated plots. Summer yields of nonirrigated plots were between 20 and 24 percent of winter yields of irrigated plots, but were 54 percent of winter yields of nonirrigated plots. The results stress the strong effect of irrigation on potato yields.

Irrigation did not affect the production of commercial-size tubers (tuber diameter > 5 cm) in the winter crop of 1981. Because irrigation was applied uniformly to both irrigated and nonirrigated plots up to 30 days after planting, the remaining soil moisture after 30 days, plus some scattered showers, probably was sufficient to sustain tuber enlargement in the nonirrigated plots.

Dry matter distribution patterns in winter and summer were similar, but plants from the irrigated and nonirrigated summer plots accumulated less dry matter in tubers than the winter crop (Table 5). The differential response in dry matter accumulation in tubers between irrigated and nonirrigated summer and winter plots appeared to be caused by differences in soil temperature (Manrique et al., 1984).

At 100 days in the winter, the total N uptake in tubers was 103 kg/ha (Figure 10). No data were obtained for N uptake in the tops and roots at 100 days. At 100 days in the summer, the total N uptake was 179 kg/ha, 75 percent of which accumulated in tubers.

The K uptake pattern was similar, but uptake was greater than for N. Total K uptake at 80 days was approximately 224 and 324 kg/ha for winter and summer, respectively. Potassium removed at 100 days in the summer was 2.5 times the amount of K fertilizer applied at planting.

The pattern of P accumulation was similar to that of both N and K (Figure 11). Phosphorus in the tubers averaged 74 percent of that contained in the whole plant at 80 days. At 100 days the total amount of P from summer growth was 28 kg/ha. Calcium (Ca), magnesium (Mg), and sulfur (S) uptake was higher in the irrigated summer plots than similar winter plots. At 100 days the total quantity of Ca was nearly equal to Mg and twice that of S; however, only 9 percent of Ca was in tubers, compared with 38 and 55 percent for Mg and S, respectively. The data in Figure 11 indicate that the tubers appear to be a less important sink for Ca, Mg, and S than for N, P, and K.

Pest and disease aspects. Isolated cases of nematode attack (*Meloidogyne javanica*) were observed in Waipio experiments during the

Table 4. Summary of potato yields in Waipio and Kukaiau (Sources: Manrique et al., 1984; Manrique, unpublished data)

Treatment	Tuber yield[1]	Grade size[2] Jumbo	Commercial	Small
	(metric tons/ha)	--------	%	--------
		Waipio		
Winter 1980				
Irrigated	34.2	33.6	42.6	23.8
Nonirrigated†	--	--	--	--
Summer 1980				
Irrigated	25.4	33.2	47.5	19.2
Nonirrigated	7.9	4.4	43.4	52.2
Winter 1981				
Irrigated	38.6	--	88.9[3]	11.1
Nonirrigated	14.6	--	89.5[3]	10.5
L.S.D. (0.05)	3.2	--	--	--
		Kukaiau		
Summer 1980				
Irrigated	39.0	49.8	31.8	18.4
Nonirrigated	36.7	52.1	28.7	19.2
Winter 1981				
Irrigated	27.8	--	50.3[3]	49.7
Nonirrigated	23.0	--	39.2[3]	60.8
L.S.D. (0.05)	5.7	--	--	--

[1] Yield corrected to a plant population of 36,666 plants/ha.
[2] Jumbo : tuber diameter > 8 cm
Commercial : tuber diameter 5-8 cm
Small : tuber diameter < 5 cm
[3] Percentage of tubers of jumbo + commercial size.
† No nonirrigated treatment was included in winter of 1980.

temperature (Bodlaender, 1963).

At the depth of tuber set (10 cm), soil temperatures in the winter and summer of 1980 were 13 to 15 °C and 23 to 27 °C, respectively. The soil temperature data in Figure 8 indicate that tüber enlargement in this Tropeptic Eutrustox of Hawaii proceeded under different soil temperatures for summer and winter seasons.

Plant growth. Tuber initiation and enlargement in the winter began just before 40 days after planting (Figure 9). Fresh tuber weight per plant in the winter of 1981 was approximately 863 g at 80 days and 1451 g at 100 days. A similar accumulation pattern was found in the winter of 1980.

Tuber initiation in the summer was delayed until 55 days after planting. The fresh tuber weight per plant in the irrigated plots was 544 g at 80 days and 1322 g at 100 days.

Without irrigation the fresh tuber accumulation rate in the winter was higher than in the summer. Since plants were taken at comparable growth periods through the season, the greater tuber accumulation rate in the winter (nonirrigated treatments) appears to be a consequence of lower soil temperatures.

The highest tuber yields were obtained in the winter season (Table 4). Yields varied between 34 and 39 metric tons/ha. Summer yields of irrigated plots were between 66 and 74 percent of winter yields of irrigated plots. Summer yields of nonirrigated plots were between 20 and 24 percent of winter yields of irrigated plots, but were 54 percent of winter yields of nonirrigated plots. The results stress the strong effect of irrigation on potato yields.

Irrigation did not affect the production of commercial-size tubers (tuber diameter > 5 cm) in the winter crop of 1981. Because irrigation was applied uniformly to both irrigated and nonirrigated plots up to 30 days after planting, the remaining soil moisture after 30 days, plus some scattered showers, probably was sufficient to sustain tuber enlargement in the nonirrigated plots.

Dry matter distribution patterns in winter and summer were similar, but plants from the irrigated and nonirrigated summer plots accumulated less dry matter in tubers than the winter crop (Table 5). The differential response in dry matter accumulation in tubers between irrigated and nonirrigated summer and winter plots appeared to be caused by differences in soil temperature (Manrique et al., 1984).

At 100 days in the winter, the total N uptake in tubers was 103 kg/ha (Figure 10). No data were obtained for N uptake in the tops and roots at 100 days. At 100 days in the summer, the total N uptake was 179 kg/ha, 75 percent of which accumulated in tubers.

The K uptake pattern was similar, but uptake was greater than for N. Total K uptake at 80 days was approximately 224 and 324 kg/ha for winter and summer, respectively. Potassium removed at 100 days in the summer was 2.5 times the amount of K fertilizer applied at planting.

The pattern of P accumulation was similar to that of both N and K (Figure 11). Phosphorus in the tubers averaged 74 percent of that contained in the whole plant at 80 days. At 100 days the total amount of P from summer growth was 28 kg/ha. Calcium (Ca), magnesium (Mg), and sulfur (S) uptake was higher in the irrigated summer plots than similar winter plots. At 100 days the total quantity of Ca was nearly equal to Mg and twice that of S; however, only 9 percent of Ca was in tubers, compared with 38 and 55 percent for Mg and S, respectively. The data in Figure 11 indicate that the tubers appear to be a less important sink for Ca, Mg, and S than for N, P, and K.

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		Jumbo	Commercial	Small
	(metric tons/ha)		%	
		Waipio		
Winter 1980				
Irrigated	34.2	33.6	42.6	23.8
Nonirrigated†	--	--	--	--
Summer 1980				
Irrigated	25.4	33.2	47.5	19.2
Nonirrigated	7.9	4.4	43.4	52.2
Winter 1981				
Irrigated	38.6	--	88.9[3]	11.1
Nonirrigated	14.6	--	89.5[3]	10.5
L.S.D. (0.05)	3.2	--	--	--
		Kukaiau		
Summer 1980				
Irrigated	39.0	49.8	31.8	18.4
Nonirrigated	36.7	52.1	28.7	19.2
Winter 1981				
Irrigated	27.8	--	50.3[3]	49.7
Nonirrigated	23.0	--	39.2[3]	60.8
L.S.D. (0.05)	5.7	--	--	--

[1] Yield corrected to a plant population of 36,666 plants/ha.
[2] Jumbo : tuber diameter > 8 cm
Commercial : tuber diameter 5-8 cm
Small : tuber diameter < 5 cm
[3] Percentage of tubers of jumbo + commercial size.
† No nonirrigated treatment was included in winter of 1980.

Table 5. Accumulation of dry matter in tops and tubers of 'Kennebec' potato

Year	Season	Treatment	Tops 40	Tops 60	Tops 80	Tops 100	Tubers 40	Tubers 60	Tubers 80	Tubers 100
			g/plant							
					Waipio					
1980	Winter	Irrigated	7.5	23.2	44.0	-‡	2.2	30.0	164.9	253.1
		Nonirrigated†	-	-	-	-	-	-	-	-
	Summer	Irrigated	9.7	66.9	93.2	64.0	- §	1.7	78.9	215.5
		Nonirrigated	9.5	31.9	41.2	26.8	- §	2.4	42.9	54.0
1981	Winter	Irrigated	13.5	48.9	36.6	-‡	2.7	77.9	181.3	247.0
		Nonirrigated	14.8	22.7	16.0	-‡	5.5	45.9	90.6	108.0
					Kukaiau					
1980	Summer	Irrigated	46.0	59.3	68.4	55.6	7.8	82.3	172.9	335.5
		Nonirrigated	33.0	43.3	67.4	54.9	3.2	12.3	128.6	212.0

† No nonirrigated treatment was included in winter of 1980.
‡ Due to leaf senescence top samples were not taken at 100 days after planting.
§ Tuber initiation began after 40 days.

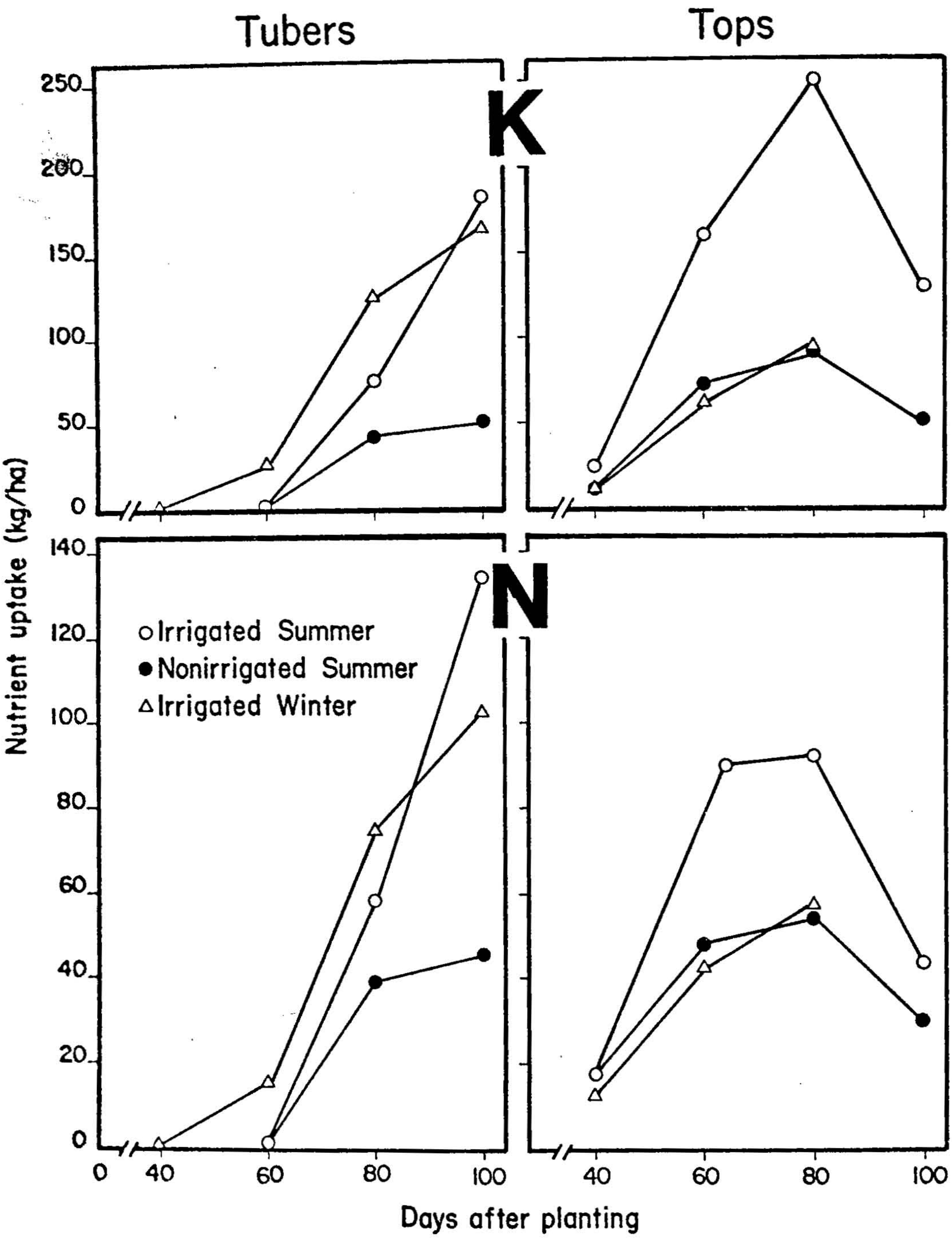

Figure 10. Effect of irrigation on N and K uptake by potato at Waipio, winter and summer 1980. (Source: Manrique et al., 1984)

Table 5. Accumulation of dry matter in tops and tubers of 'Kennebec' potato

			Days after planting							
			40	60	80	100	40	60	80	100
Year	Season	Treatment	Tops				Tubers			
			g/plant							
			Waipio							
1980	Winter	Irrigated	7.5	23.2	44.0	-‡	2.2	30.0	164.9	253.1
		Nonirrigated†	-	-	-	-	-	-	-	-
	Summer	Irrigated	9.7	66.9	93.2	64.0	- §	1.7	78.9	215.5
		Nonirrigated	9.5	31.9	41.2	26.8	- §	2.4	42.9	54.0
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		Nonirrigated	14.8	22.7	16.0	-‡	5.5	45.9	90.6	108.0
			Kukaiau							
1980	Summer	Irrigated	46.0	59.3	68.4	55.6	7.8	82.3	172.9	335.5
		Nonirrigated	33.0	43.3	67.4	54.9	3.2	12.3	128.6	212.0

† No nonirrigated treatment was included in winter of 1980.
‡ Due to leaf senescence top samples were not taken at 100 days after planting.
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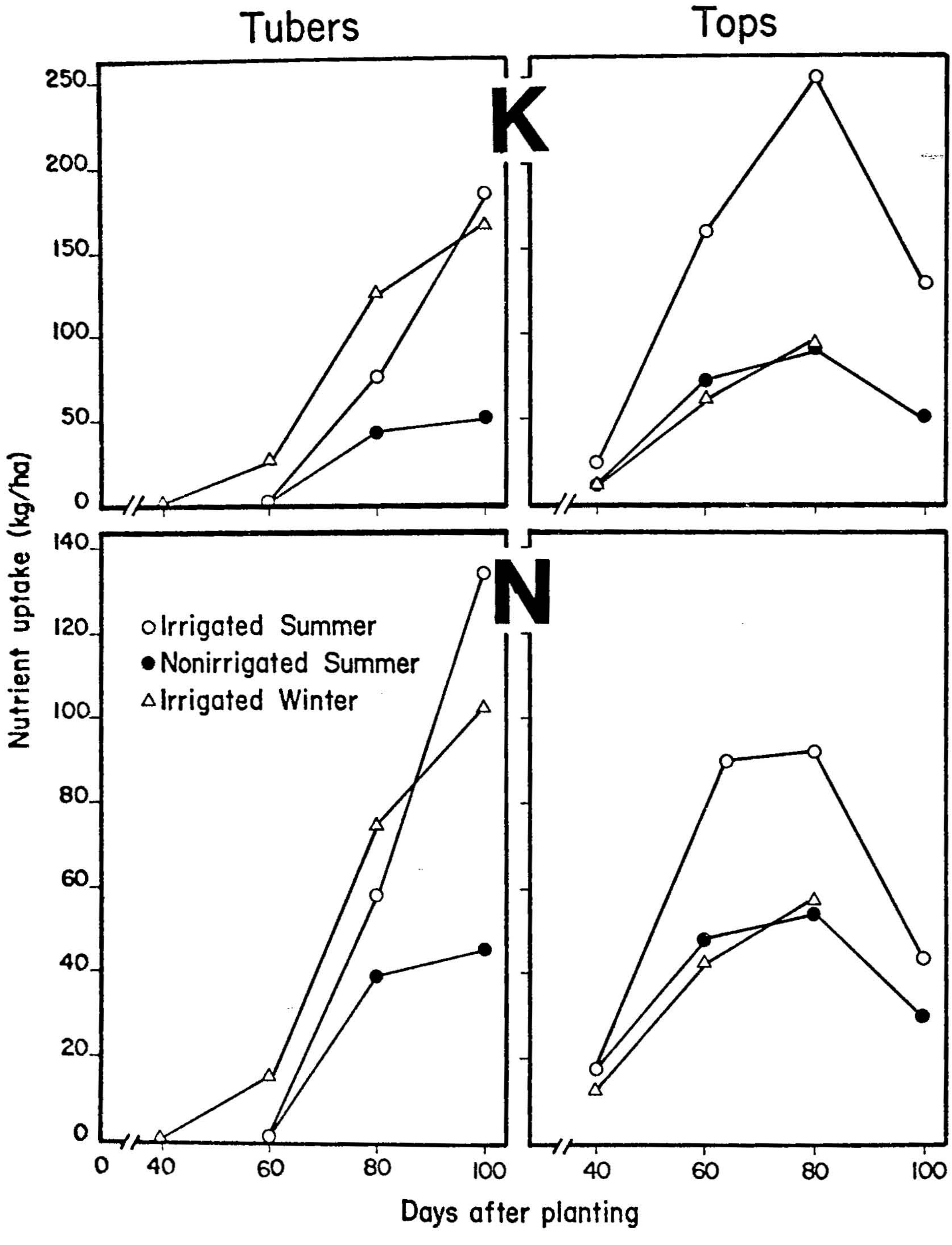

Figure 10. Effect of irrigation on N and K uptake by potato at Waipio, winter and summer 1980. (Source: Manrique et al., 1984)

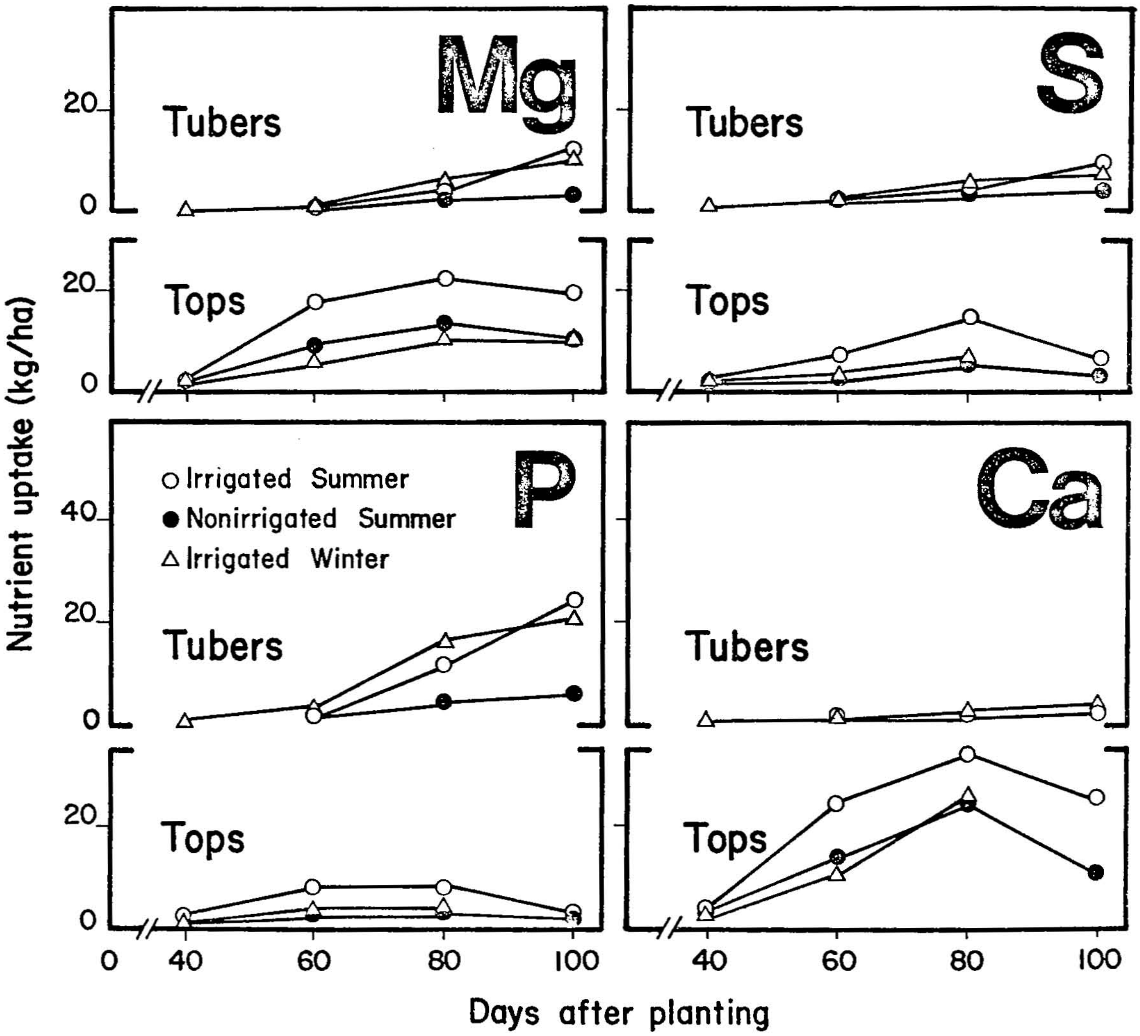

Figure 11. Effect of irrigation on P, Ca, Mg, and S uptake by potato at Waipio, winter and summer 1980. (Source: Manrique et al., 1984)

Table 6. Rainfall, pan evaporation, potential evapotranspiration, and air temperature for Kukaiau (island of Hawaii) (Source: Benchmark Soils Project, University of Hawaii)

Year	Month	MAT (1)	Rainfall	ETP (2)
		(°C)	- - - - - - mm	- - - - - -
1980	January	21.9	114.0	84.9
	February	22.5	194.0	90.7
	March	20.8	1319.6	67.1
	April	21.0	863.4	85.6
	May	23.2	124.6	125.0
	June	23.3	81.5	135.3
	July	23.7	63.1	128.9
	August	23.8	39.8	128.7
	September	23.8	178.3	111.7
	October	23.1	217.2	100.0
	November	23.3	102.6	95.7
	December	21.0	81.2	85.1
1981	January	20.0	7.4	98.9
	February	19.3	120.4	93.9
	March	19.1	109.6	--†
	April	19.9	13.4	--

(1) Mean air temperature.
(2) Potential evapotranspiration (Hargreaves method, 1974).
† Data not available.

winter season. No symptoms at all were observed in the summer. It appears that the soil of this experiment has a low native nematode population, as a probable result of the long period that the soil remained uncultivated. Absence of nematode attack in the summer also may indicate that nematode survival is related to availability of water. Keeping the soil dry in fallow periods may reduce nematode populations. Waipio, which has several dry months each year (ustic soil moisture regime), seems to provide an excellent environment for natural nematode control unless continually irrigated (W. Apt, University of Hawaii, personal communication, 1983).

Rhizoctonia (*Rhizoctonia solani*) was the main problem in winter potato production at Waipio. Seed and soil treatment with pentachloronitrobenzene partially reduced rhizoctonia infection. In spite of the use of disease-free seed, infection was serious, suggesting that this fungus was probably already present in the soil. Environmental conditions such as low temperatures and high humidity favored rhizoctonia infection in the winter of 1980. A less severe infection occurred in the winter of 1981. No yield reduction was observed, but tubers were infected at the apex.

The relatively high soil temperatures in the summer favored the attack of several pests including the red spider mite. Mite attack was partially controlled with application of Dicofol. The high solar radiation and high soil temperatures at Waipio during the summer caused sunburn of exposed tubers, secondary growth, and jelly end rot. Although sunburn can be reduced by repeated hillings, no effective control is available at the present time for secondary growth and jelly end rot. Irrigation helped to lower soil temperatures (Manrique et al.,1984), but not sufficiently to overcome excessively high soil temperatures during the summer months.

Hydric Dystrandepts

The Hydric Dystrandepts are volcanic ash soils belonging to the Kukaiau series. They are located on uplands (150–450 m) near Honokaa in the northeast portion of the island of Hawaii. These soils are devoted to sugarcane production at the present time, but they may be used for diversified agriculture in the future.

Agroenvironment. The Kukaiau soils are well-drained, silty clay loam derived from volcanic ash. The surface layer of these soils is dark and is related to the high organic matter content (Table 2). The subsurface is medium to slightly acid with very little exchangeable aluminum (Al).

The Kukaiau soils have an udic moisture regime. Rainfall exceeded evapotranspiration in seven months of the year in 1980 (Table 6). In normal years such as 1980, rainfall in the winter months exceeded evapotranspiration by several times; however, the winter of 1981 was unusually dry. Air temperature in the winter and summer months was between 19 and 20°C and between 23 and 24°C, respectively.

Soil temperatures of irrigated plots in Kukaiau during the summer of 1980 are presented in Figure 12. Seventy-two days after planting, the minimum soil temperatures were 19, 20, and 22 °C at the soil surface, at 10 cm, and at 20 cm depth, respectively. Maximum soil temperatures were 24, 22, and 23 °C at the soil surface, at 10 cm, and at 20 cm depth, respectively. Data in Figure 12 indicate the temperature varied little between day and night.

Plant growth. At Kukaiau, tuber initiation began at 40 days after planting in both the summer of 1980 and the winter of 1981 (Figure 13). Tuber fresh weight per plant in the summer of 1980, however, was higher than that in the winter of 1981. A greater fresh tuber accumulation per plant was expected

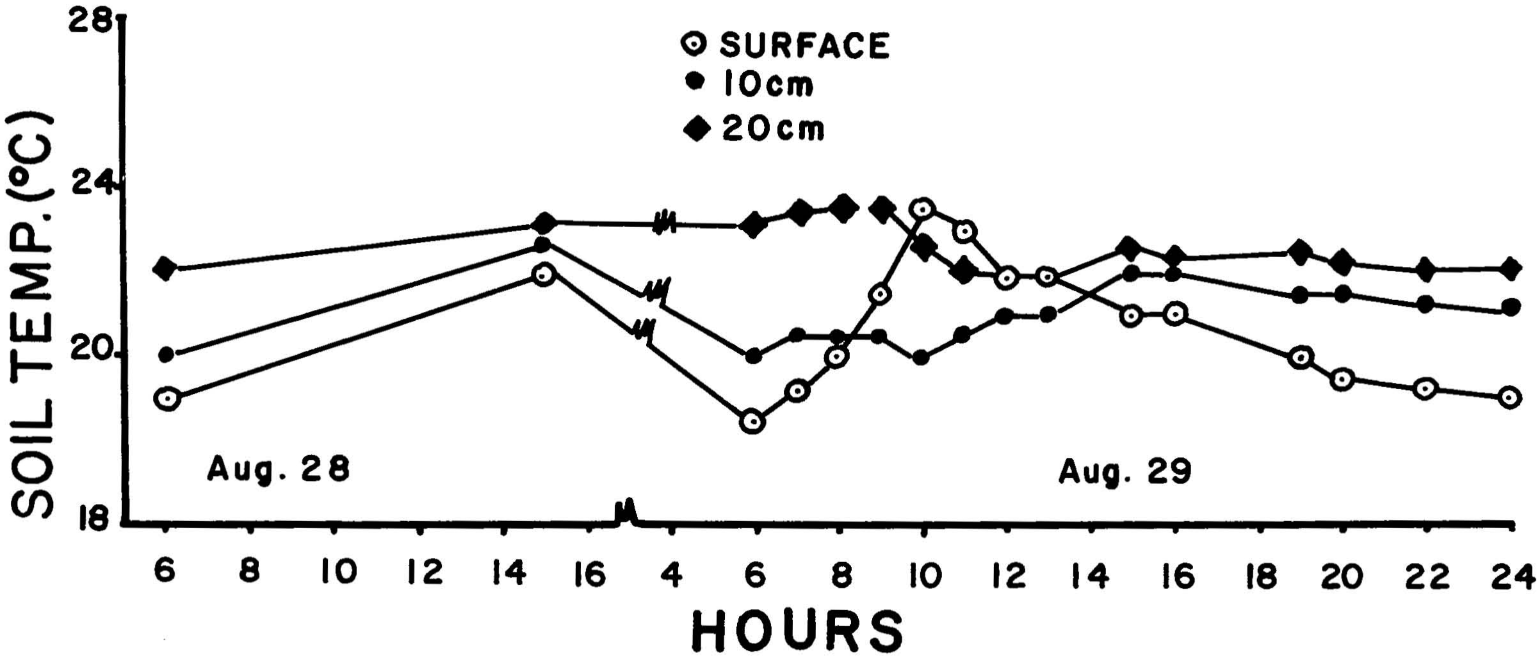

Figure 12. Soil temperature measured at various depths in irrigated potato plots at Kukaiau, summer 1980.

in the winter of 1981 since optimum soil temperatures (data not shown) and air temperatures for tuber enlargement were recorded during the winter months of 1981 (Table 6). However, a drought on the island of Hawaii prevented irrigation of the plots. This affected tuber enlargement after tuber initiation. In general, the fresh tuber weight accumulation trends (Figure 13) resemble those previously reported for Waipio and Kohala. The greater tuber yields on irrigated than on nonirrigated plots stress the point that even in udic moisture regimes such as the Hydric Dystrandept of Kukaiau, irrigation is essential to produce potatoes.

Yields at Kukaiau ranged from 23 to 39 metric tons/ha (Table 4). Problems with irrigation and a severe rhizoctonia infestation in the winter of 1981 reduced yields of irrigated plots to 71 percent of yields of irrigated summer plots. Although tuber yields were lower on nonirrigated plots, the effect of irrigation was not as great as it was in Waipio and Kohala. Unlike Waipio, where the highest yields were obtained during the winter season, the high yields at Kukaiau in the summer reveal that in environments such as Kukaiau, the differences in yield between seasons were due to differences in availability of water rather than to seasonal temperature variation.

No major differences in dry matter production were found between summer and winter seasons, thus only the dry matter distribution pattern for the summer of 1980 is reported here (Table 5).

The dry matter distribution pattern at Kukaiau was similar to that at Waipio. However, potato plants at Kukaiau accumulated more dry matter at 40 days. The maximum dry matter accumulation in tops occurred at 80 days. The decline in dry matter accumulation after 80 days coincided with senescence. Accumulation of dry matter in tubers was linear with time during most of the growing season. Although Kukaiau and Waipio had similar patterns, potato plants in Kukaiau accumulated more dry matter in tubers. At 100 days, for example, tuber dry weight per plant in irrigated plots in Kukaiau was 335 g, compared to 250 g/plant in irrigated plots in Waipio.

Lack of irrigation in Kukaiau markedly reduced the accumulation of dry matter in tubers. At 100 days, tuber dry weight per plant in nonirrigated plots was 63 percent of tuber dry weight in irrigated plots.

Nitrogen uptake in Kukaiau experiments was quite different from Waipio (compare Figures 10 and 14). The Kukaiau pattern was characterized by a large initial N accumulation in the tops. At 40 days in irrigated plots, total N uptake in tops in Kukaiau was approximately 72 kg/ha compared to 14 kg/ha in Waipio. The maximum accumulation of N in tops in Kukaiau occurred at 60 days. Later in the season the tubers became the main sink for N assimilates, and N accumulated in tops was either translocated to the tubers or was lost through leaf drop. Nitrogen uptake in tubers was also higher in Kukaiau than in Waipio. At 100 days, N uptake in tubers was 168 and 134 kg/ha for Kukaiau and Waipio irrigated plots, respectively.

The K uptake pattern at Kukaiau was similar to that of Waipio although total K uptake was greater. Similarly to N, peak K uptake was reached at 60 days for tops (Figure 14). At 100 days, total K uptake was 360 kg/ha, 73 percent of which was accumulated in tubers. Potassium removed at 100 days was 2.2 times the amount of fertilizer applied at planting.

Phosphorus content in tops was almost constant throughout the season (Figure 15). The tubers, however, accumulated quite high amounts of P compared to values reported in the literature (Harris, 1978, p. 200). The total P uptake at 100 days was 33 kg/ha. Calcium accumulated in the tops with little translocation to tubers. Magnesium and S uptake

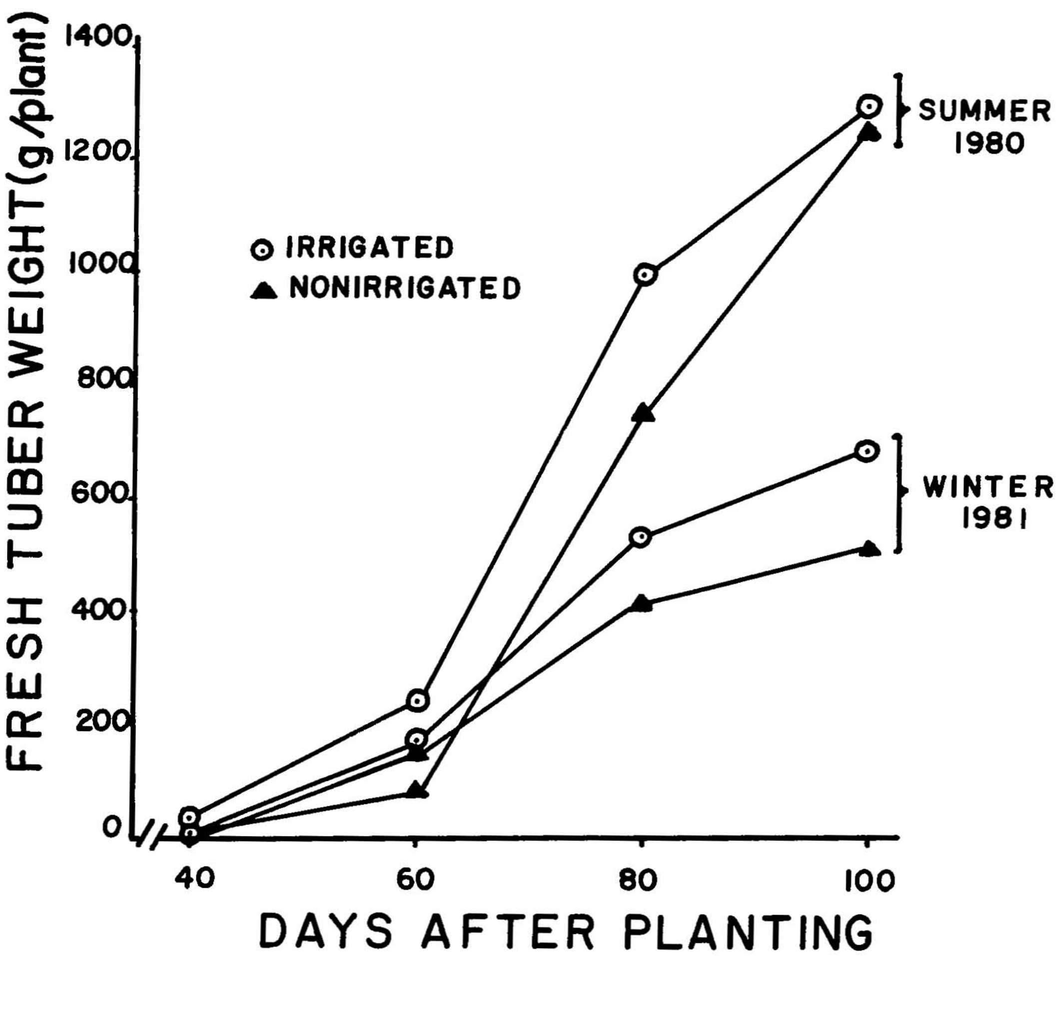

Figure 13. Effect of irrigation on accumulation of fresh weight in potato tubers at Kukaiau, summer 1980 and winter 1981.

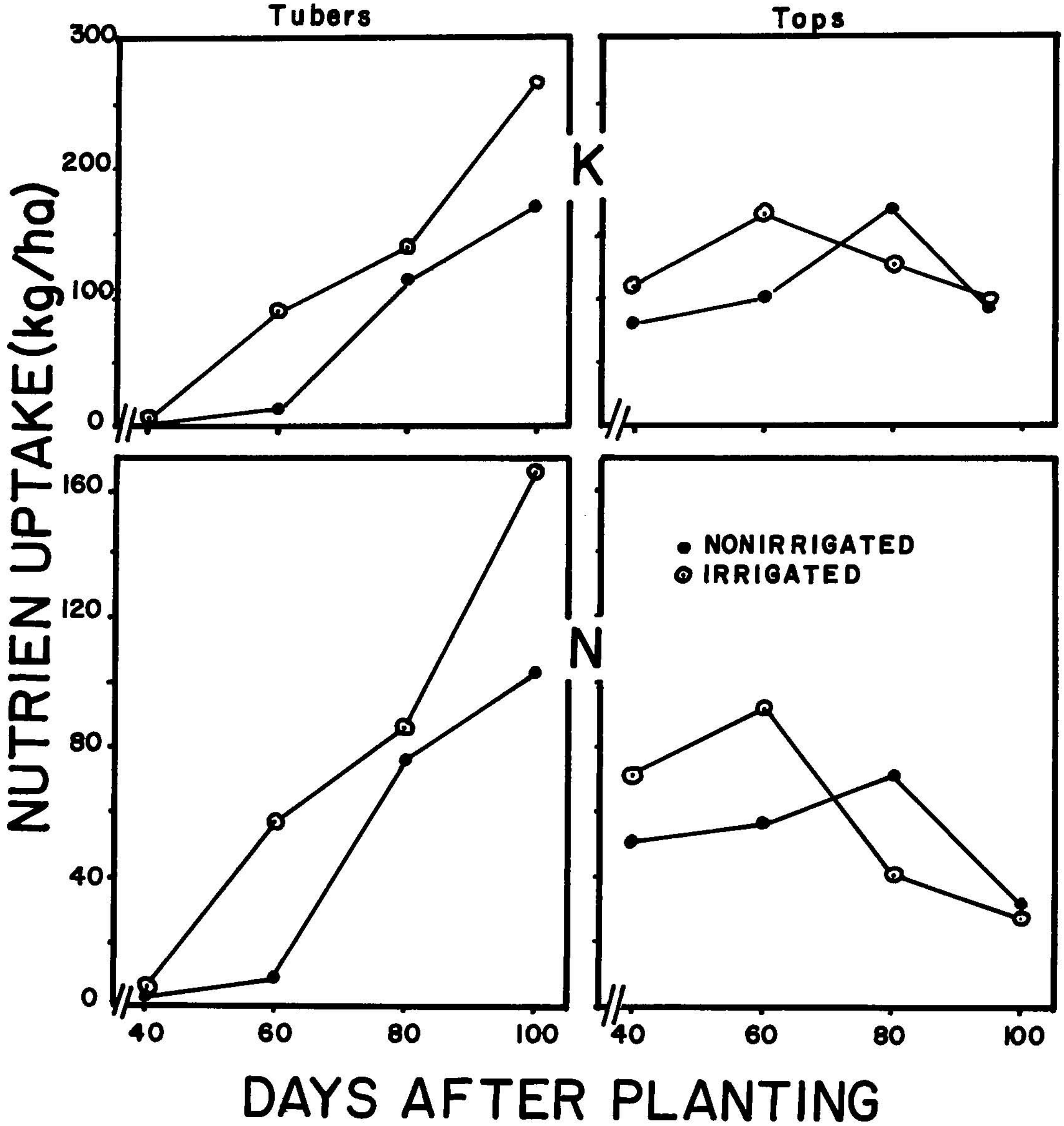

Figure 14. Effect of irrigation on N and K uptake by potato at Kukaiau, summer 1980.

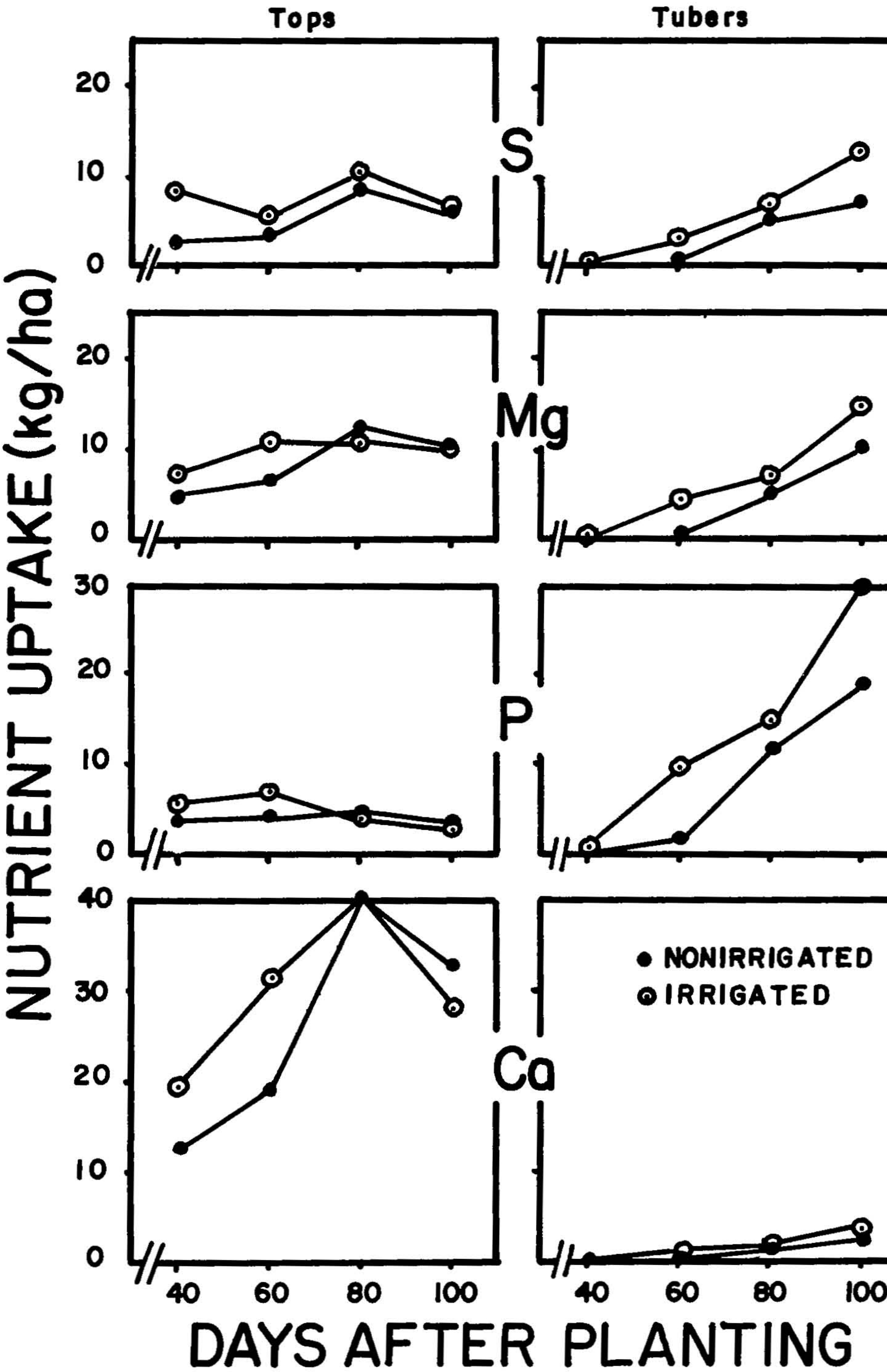

Figure 15. Effect of irrigation on P, Ca, Mg, and S uptake by potato at Kukaiau, summer 1980.

at Kukaiau was higher than at Waipio (compare Figures 11 and 15). The total uptake for Mg and S at 100 days was approximately 25 and 19 kg/ha, respectively.

Pest and disease aspects. Symptoms of nematode attack were observed late in the summer of 1980 in Kukaiau. Plant roots were particularly infested with root-knot nematode (*Meloidogyne javanica*) in irrigated plots.

Although *M. javanica* attack can reduce tuber yields and disturb nutrient uptake (Jensen et al., 1979), no signs of changes in either yields or plant composition were found. Symptoms of nematode attack in heavily infested plants were the presence of knots on the roots, several misshapen tubers, and the formation of small, green aerial tubers. Potatoes were planted a second time in an adjacent plot in the winter of 1981, but no symptoms of nematode attack were observed.

A heavy rhizoctonia (*Rhizoctonia solani*) infection occurred in the winter crop of 1981. Plants showed severe symptoms of water stress, and only few small underground tubers and aerial tubers were formed. Yields declined as a result, and the percentage of small tubers (diameter < 5 cm) increased (Table 4). Some symptoms of rhizoctonia infection were observed in the summer crop of 1980. Soil and seed treatment with pentachloronitrobenzene was inadequate to control the disease.

Kukaiau also has an environment favorable for the development of late blight (*Phytophthora infestans*). Cool and humid nights are common in Kukaiau, and late blight infections have been reported in adjacent areas (Ito et al., 1978; Sekioka et al., 1974). No symptoms of late blight infections were reported in the Kukaiau experiments; however, weekly preventive applications of chlorothalonil were made during the summer of 1980.

Overall Agronomic Assessment

Yield performances of the cultivar 'Kennebec' at several locations in Hawaii and the northeastern United States are used in further comparisons with yields obtained in the Hawaii environments. Table 7 shows that previous experiences with 'Kennebec' in Hawaii were unsatisfactory. Yields fluctuated from 1 to 36 metric tons/ha with an average of 13.4 metric tons/ha. The low yields were attributed to heavy late blight infestations (Ito et al., 1978; Sekioka et al., 1974); however, it is probable that a combination of heavy late blight infestation, improper growing season, and infertile soils contributed to low yields. The performance of 'Kennebec' in the northeastern United States during 1980 was excellent (Table 8). Yields were as high as 75 metric tons/ha with an overall average of 42 metric tons/ha.

Yields of 'Kennebec' in the northeastern United States provide a standard with which to compare potato yields from the Hawaii environments. In the best season, average yields in irrigated plots in Waipio and Kukaiau were comparable to yields from Pennsylvania, West Virginia, New Brunswick (Canada), and Newport (Maine). Waipio and Kukaiau yields were 81 percent of yields from Grand Isle and Presque Isle (Maine), Massachusetts, Vermont, and Connecticut; and 52 percent of yields in Tully (New York) and Rhode Island.

The differences in yields between New York and Rhode Island locations and the Hawaii environments probably indicate that crop and soil management practices in Hawaii can be improved. In fact, the results and observations from each environment suggest practices that need improving. First, the total uptake of major elements at Kukaiau and Waipio shows that the potato crop absorbed between 1.5 and 2.0 times the amount of fertilizer applied. Second, there was considerable seasonal variation in tuber yields in isohyperthermic environments. Third, although relatively standard practices of crop management were followed (irrigation, fer-

Table 7. Yield of 'Kennebec' potato in Hawaii (Source: Ito et al., 1978; Sekioka et al., 1974)

Year	Soil and location	Yield	Remarks
		(metric tons/ha)	
1968-1971	Andept, Volcano (1200 m), Hawaii	19.9	--
1968-1971	Andept, Lalamilo (750 m), Hawaii	16.3	--
1968-1971	Andept, Lamb Brothers (900 m), Hawaii	0.9	--
1968-1971	Kauai (165 m), Kauai	10.8	--
-†	Andept, Volcano (1200 m), Hawaii	9.3	May-Sept., severe late blight infestation.
-	Andept, Volcano (1200 m), Hawaii	36.3	Sept.-Jan.
-	Andept, Volcano (1200 m), Hawaii	9.5	Dec.-April, severe late blight infestation.
-	Andept, Lalamilo (750 m), Hawaii	13.6	June-Oct., severe late blight infestation.
-	Kauai (165 m), Kauai	3.6	June-Oct.

† No information available on year.

Table 8. Yield of 'Kennebec' potato in some selected locations in the continental United States (Source: Murphy et al., 1981)

Location	Year	Planting date	Harvest date	Yield[1]	Remarks
				(metric tons/ha)	
Dover, Delaware	1980	April 18	Aug. 6	11.7	Wet conditions
Grand Isle, Maine	1980	May 23	Sept. 20	43.0	
Presque Isle, Maine	1980	May 20	Sept. 15	49.6	
Newport, Maine	1980	May 29	Oct. 8	36.5	
Massachusetts	1980	May 15	Sept. 23	47.4	
New Brunswick, Can.	1980	May 21	Sept. 11	38.4	
Guildhall, Vermont	1980	May 21	Sept. 30	46.0	
Tully, New York	1980	May 3	Sept. 18	71.2	
Lehigh, Penn.	1980	May 6	Sept. 15	12.1	Extreme dry conditions
Connecticut	1980	May 5	Sept. 30	43.1	
Somerset, Penn.	1980	May 16	Sept. 15	39.6	
Rhode Island	1980	April 30	Sept. 29	74.5	
West Virginia	1980	May 18	Sept. 9	33.6	
Average				42.1	

[1]Yield above 1 1/2 inches (3.75 cm).

tilization, disease-free planting materials), the control of diseases and pests was less than adequate to assure optimum yields. Fourth, plant population was low as a consequence of rotten seeds and further disease infection, and led to low yields. Improved crop and soil management should include the application of higher rates of fertilizers, increased plant population, the use of certified disease-free planting materials together with an integrated disease and pest management system, and finally, potatoes should be planted in the most suitable season. These improved practices should increase tuber yields by at least 50 percent.

The above practices are recommended for all Hawaii environments under study. However, each environment has particular conditions in which potato production should be planned and conducted. Potato production in isohyperthermic environments such as Waipio and Kohala should be conducted as a component of a cropping system. A corn-soybean-potato cropping pattern has been successfully tested at Waipio (Manrique et al., 1980). This pattern takes advantage of the warm, sunny periods between April and November to grow corn and soybean. Potato, which requires cool soil temperatures for tuber initiation and enlargement, is grown in the winter months.

Irrigation is crucial for successful potato production at Waipio and Kohala. Even in the winter months, when most of the rainfall occurs, supplementary irrigation is essential for maximum plant growth. Wind frequently reduces yields at Kohala. However, wind damage can be reduced with high plant population, fertilizer application, and irrigation. Windbreaks such as the fine net used in the Kohala experiment control wind damage, but the high cost limits its use on a field scale.

The results from Waipio suggest potatoes should not be grown during the summer. Yields with 'Kennebec' will be reduced because of the high temperatures and high incidence of diseases and pests. However, the results from Waipio are relevant in the evaluation of potato performance in isohyperthermic environments with minimal season variation. 'Kennebec' matures in 120 days in the summer compared with about 100 days during the winter, largely because tuber initiation is delayed by 15 days. As soon as tuber initiation begins in the summer, fresh and dry matter accumulation of tubers are similar or even greater than during the winter. These results reveal an unexpected potential for potato production in the tropics if tuber initiation can be accelerated. Because tuber initiation is probably dependent on soil temperature, research on ways to manipulate soil temperature may be productive. Irrigation can lower soil temperatures (Manrique et al., 1984) but may not compensate for excessively high temperature. The development of heat-tolerant varieties may permit potato adaptation to tropical environments.

Seasonal temperature variation is less critical at Kukaiau. Kukaiau has soil temperatures that are suitable for potato production all year 'round. However, potato production in Kukaiau as a monoculture is not recommended because of the risk of a progressive buildup of diseases and pests. Crop rotations designed to keep diseases and pests below damaging levels are probably the most viable alternative. The use of chemicals as well as disease-tolerant varieties will also be important in disease control.

Availability of seed is the main constraint to developing a profitable potato industry in Hawaii. Local potato seed production will be necessary to eliminate the cost of buying and shipping potato seeds from the U.S. mainland. Adequate local environment and infrastructure exist for profitable potato seed production. Unlike other places in tropical regions, Hawaii possesses extensive upland areas that are suitable for potato seed production on a commercial scale. Examples of these environments are the upland areas of Mililani and Wahiawa on the island of Oahu, and the upland areas around Mauna Kea and Mauna Loa volcanoes on the island of Hawaii. The technology needed to produce seed potatoes is available elsewhere, and the University of Hawaii and the agricultural experiment stations should undertake the task to profitably produce potato seeds.

Diseases and pests cause uncertainty in potato production in Hawaii. An integrated pest and disease control program is needed for improving and maintaining yield and tuber quality. Disease control should involve the use of disease-free seeds, plant-protective chemicals, disease-tolerant varieties, and crop rotations. Nematodes are not currently a problem for potatoes in Hawaii (W. Apt, University of Hawaii, personal communication, 1983). Soil fumigation, however, would be necessary in severely infested areas.

Disease control measures should be supported by research on disease control and prevention. Also, legislation is needed to prevent the introduction of new diseases. Because potatoes are not an agricultural commodity, quarantine regulations of potato shipment to Hawaii are somewhat relaxed. The risk of introducing disease is much higher with potatoes than with other crops. Extension education at the farmer level, especially at the potato home-grower level, should be increased to assure effective disease control. As an example, the common practice of obtaining seed from the local market, which has been the cause of outbreaks and crop failures in Hawaii, should be thoroughly discouraged.

Another important aspect in the agronomic assessment of potato production in Hawaii is the availability of lands suitable for potato production. Manrique (1982) assessed the suitability of many Hawaii soils for potato production under different levels of input (Table 9). At zero-input level, which implies the use of the land under natural conditions and without application of inputs, 85 percent of the soils were considered unsuitable for potato production. Nutrient and water availability were the main constraints. At low-input level, a situation where the subsistence farmer operates, 75 percent of the soils were considered unsuitable for potato production. Unlike some other tropical food crops such as cassava and sweet potatoes, potatoes benefit little from a small application of fertilizers. The application of high levels of input, such as fertilizers, amendments, irrigation, and drainage practices, made 95 percent of the Hawaiian soils highly suitable for potato production.

On the island of Hawaii, some of these highly suitable soils cover an approximate area of 76,000 acres (34,547 ha) (Table 10). Presently, most of these soils are under sugarcane and pasture production. Among these soils, the Akaka soil series is the most likely to be used for potato production. It has the best environment (isomesic soil temperature regime) and is about 20 times the area required to produce sufficient potatoes to supply local needs.

ECONOMIC ASSESSMENT

The analysis of agronomic aspects of potato production in the Hawaii environments indicates that with careful pest and disease control it is agronomically feasible to produce potatoes in Hawaii. However, some economic aspects need to be assessed to determine if potato production is also a profitable activity. The agronomic results indicate that yield and tuber quality can probably be improved by the use of appropriate technology. Application of technology, however, implies increasing expenditures on seeds, fertilizers, chemicals, machinery, storage facilities, transportation, and marketing. The simple benefit-cost analysis (B/C) shown in Table 11 indi-

Table 9. Suitability of Hawaiian soils for potato production (Source: Manrique, 1982)

	Suitability[1]								
	ZIL			LIL			HIL		
Soil series	Order[2]	Class[3]	Suitab.	Order	Class	Suitab.	Order	Class	Suitab.
Akaka	U	4	PARU	U	4	PARU	S	1	GOOD
Apakuie	S	3	POOR	S	3	POOR	S	1	GOOD
Ewa	U	4	PARU	U	4	PARU	S	1	GOOD
Haiku	U	4	PARU	U	4	PARU	S	1	GOOD
Hanalei	U	5	PERU	U	5	PERU	S	1	GOOD
Hoolehua	U	4	PARU	U	4	PARU	S	1	GOOD
Io	S	3	POOR	S	3	POOR	S	1	GOOD
Kalae	S	3	POOR	S	3	POOR	S	1	GOOD
Kapaa	U	4	PARU	U	4	PARU	S	1	GOOD
Kawaihae	U	4	PARU	U	4	PARU	S	1	GOOD
Keahua	U	4	PARU	U	4	PARU	S	1	GOOD
Kohala	U	4	PARU	U	4	PARU	S	1	GOOD
Lahaina	U	4	PARU	U	4	PARU	S	1	GOOD
Lawai	U	4	PARU	U	4	PARU	S	1	GOOD
Lihue	U	4	PARU	U	4	PARU	S	1	GOOD
Lualualei	U	5	PERU	U	5	PERU	S	3	POOR
Mahana	U	4	PARU	S	3	POOR	S	1	GOOD
Molokai	U	4	PARU	U	4	PARU	S	1	GOOD
Kukaiau	U	4	PARU	U	4	PARU	S	1	GOOD
Wahiawa	U	4	PARU	U	4	PARU	S	1	GOOD

[1]ZIL = Zero-input level, LIL = Low-input level, HIL = High-input level.
[2]U = Unsuitable, S = Suitable.
[3]Classes: 1(GOOD), 2(FAIR), 3(POOR), 4(PARU = partially unsuitable), 5(PERU = permanently unsuitable).

Table 10. Approximate area of some highly suitable soils for potato production, island of Hawaii (Source: Sato et al., 1973)

No.	Soil series	Slope steepness	Area	Soil temperature regime
		(%)	(Acres)	
1	Akaka silty clay loam	0-10	19,468	isomesic
		10-20	5,181	
2	Apakuie, very fine sandy loam	10-20	11,371	isomesic
3	Kawaihae, extremely stony, very fine sandy loam	6-12	22,106	isohyperthermic
4	Kohala silty clay	0-3	2,721	isohyperthermic
		3-12	6,013	
		12-20	971	
5	Kukaiau silty clay loam	6-12	2,871	isothermic
		12-20	5,301	
	Total		76,003	

Table 11. Benefit-cost analysis for potato production, Hawaii 1982

Item	Amount	Unit value	Total value
Costs		- - - Dollars	- - -
Seeds,[1] lb	6000	0.20	1200
Fertilizers, metric tons			
Nitrogen (200 kg N/ha)	0.5	270.00	135
Phosphorus (200 kg P_2O_5/ha)	0.5	237.00	118
Potassium (200 kg K_2O/ha)	0.5	230.00	115
Chemicals	-	-	100
Machinery, hours			
Planting and harvesting	5	20.00	100
Hilling	3	20.00	60
Labor, hours			
Planting	24	5.00	120
Hilling	16	5.00	80
Spraying	24	5.00	120
Harvesting	24	5.00	120
Storage and Transportation	-	-	300
Total			2568
Benefits			
Yield,[2] lb	44,247	0.10	4425
Benefit-cost ratio (B/C)	-	-	1.72

[1] Estimated seed to obtain a plant population of 45,000 plants/ha.
[2] Estimated yield of 20 metric tons/ha.

cates that it is economically feasible to produce potatoes in Hawaii. The B/C can be increased if production costs are lowered. For example, seed cost, which accounts for 55 percent of the total cost, would decrease if seeds were locally produced. Also, the production of potatoes on a field scale should lower some expenditures such as machinery, labor, transportation, and so on.

Finally, marketing is an aspect of potato production that is as important as any other factor. Previous review of the literature indicated that by 1985 Hawaii will need 44 million lb of potatoes to cover local consumption. Hence, the problem is not one of marketability, because that already exists and is likely to grow steadily in the near future. The question that arises is whether local growers can compete with U.S. mainland growers for the local market. For many decades, U.S. potato growers have been shipping potatoes to Hawaii. Most of the inshipments were and still are for food processing, but a small fraction is consumed as a fresh product. Because local people like to consume homegrown products, the market for fresh potatoes is likely to be covered by local production. However, in order to capture the local market for potato processing, Hawaiian growers have to produce potatoes at lower prices than U.S. mainland growers, and provide a dependable, high quality supply. Varietal research and agronomic practices to produce high quality potatoes for processing are, therefore, of prime importance to control the local market.

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